FAREWELL TO FLUORESCENT LIGHTING: HOW A PHASEOUT CAN CUT MERCURY POLLUTION, PROTECT THE CLIMATE, AND SAVE MONEY

Jennifer Thorne Amann,
Brian Fadie, Joanna Mauer,
Kanchan Swaroop, and
Carolin Tolentino

March 2022
Report

ACEEE
Smart Energy. Clean Planet. Better Lives.
clasp
Efficient Appliances for People & the Planet
ASAP | APPLIANCE STANDARDS AWARENESS PROJECT
Clean Lighting Coalition

Contents

About Us

The **American Council for an Energy-Efficient Economy** (ACEEE), a nonprofit research organization, develops policies to reduce energy waste and combat climate change. Its independent analysis advances investments, programs, and behaviors that use energy more effectively and help build an equitable clean energy future.

The **Appliance Standards Awareness Project** (ASAP) organizes and leads a broad-based U.S. coalition that works to advance and defend new appliance, equipment, and lighting standards that deliver large energy and water savings, monetary savings, and environmental benefits. ASAP is led by a steering committee that includes representatives from energy and water efficiency organizations, the environmental community, consumer and low-income advocacy groups, utilities, and state government.

CLASP serves at the epicenter of collaborative, ambitious efforts to mitigate climate change and in the global movement for clean energy access, through appliance efficiency. CLASP works hand-in-hand with governments, experts, industry, consumers, donor organizations and others to propel policies and markets toward the highest-quality, lowest resource-intensive products possible. CLASP has worked in more than 100 countries since its inception in 1999.

The **Clean Lighting Coalition** is a global partnership coordinated by CLASP to capture the health and environmental benefits of eliminating mercury-based lighting.

About the Authors

Jennifer Thorne Amann promotes residential and commercial whole-building performance improvements, explores approaches to increasing equitable outcomes in efficiency programs and policies, and analyzes the impacts of stronger building efficiency codes and standards. She has authored dozens of publications and articles on efficient products and practices, emerging residential and commercial building technologies, and the progress of market transformation initiatives, among others. In addition, Jennifer leads content development for ACEEE's consumer-facing website SmarterHouse.org. She serves on the boards of directors of the Attachments Energy Rating Council and the Resource Innovation Institute. Before joining ACEEE in 1997, she worked in community organizing and education on a variety of environmental and consumer issues. Jennifer earned a master of environmental studies from the Yale School of Forestry and Environmental Studies and a bachelor of arts in environmental studies from Trinity University.

Carolin Tolentino assists the buildings team with research on energy codes and low- and zero-energy buildings. She joined ACEEE in 2020. Prior to ACEEE, Carolin was an intern at ICLEI—Local Governments for Sustainability, assigned to the sustainable resources team. Before that, she interned with the education department at Urban Green Council. Carolin earned a bachelor of arts in environmental policy and German studies from Rice University.

Joanna Mauer is the technical advocacy manager for ASAP. She leads ASAP's technical advocacy on U.S. Department of Energy efficiency standards for residential appliances and commercial and industrial equipment. Prior to joining ASAP, Joanna worked at the U.S. Environmental Protection Agency and the Center for Integrative Environmental Research. She also served as a Peace Corps volunteer in the Dominican Republic. Joanna received a master of public policy from the University of Maryland and a bachelor of science in civil and environmental engineering from Cornell University. She has been with ASAP since 2010.

Kanchan Swaroop is a technical advocacy associate with ASAP. She advocates for improved national efficiency standards for various appliances and equipment. She also conducts analysis and provides technical support for ASAP's state standards advocacy. Kanchan worked as a project engineer at Air Liquide before coming to ASAP in 2020. She attended the University of Michigan, where she received a master of science in environmental engineering, a master of science in environment and sustainability, and a bachelor of science in chemical engineering.

Brian Fadie is a state policy associate with ASAP, helping to organize and lead a broad-based coalition effort that works to advance appliance, equipment, and lighting standards. Prior to joining ASAP, Brian worked on state and local renewable energy and energy efficiency public policy at the Montana Environmental Information Center. Brian holds a master of science in environmental policy and planning from the University of Michigan as well as a bachelor of science in psychology and a bachelor of arts in communication from Michigan State University.

Acknowledgments

This report was made possible through the generous support of the CLASP. The authors gratefully acknowledge the external reviewers, internal reviewers, colleagues, and sponsors who supported this report. External expert reviewers included Ana Maria Carreño and Michael Scholand (CLASP) and Noah Horowitz (NRDC). External review and support do not imply affiliation or endorsement. We acknowledge the project support and internal review provided by Andrew deLaski and Steve Nadel. We also acknowledge data gathering provided by Alicia Culver (Responsible Purchasing Network). Last, we would like to thank Mary Robert Carter for managing the editing process, Mariel Wolfson for developmental editing, Elise Marton for copy editing, Roxanna Usher for proofreading, Kate Doughty for graphic design, and Ben Somberg and Wendy Koch for their help in launching this report.

Suggested Citation

Amann, J. T., B. Fadie, J. Mauer, K. Swaroop, and C. Tolentino. 2022. Farewell to Fluorescent Lighting: *How a Phaseout Can Cut Mercury Pollution, Protect the Climate, and Save Money*. Washington, DC: American Council for an Energy-Efficient Economy. www.aceee.org/research-report/b2202.

Executive Summary

KEY FINDINGS

- Mercury-free LED replacements for linear and compact fluorescent lamps (i.e., light bulbs) are widely available and provide the same or better lighting service, longer product life, and much lower total cost.
- Rapidly phasing out most fluorescent lighting would prevent lamps containing 16,000 pounds of mercury from being sold and installed through 2050, reducing a substantial source of mercury pollution in our air and soil.
- Electricity savings from a complete transition to LED lighting would cut annual carbon dioxide emissions in 2030 by 18 million metric tons, an amount equal to the annual emissions of four million typical passenger cars. On a cumulative basis, a phaseout would cut carbon dioxide emissions by more than 200 million metric tons through 2050.
- The modest additional cost of LED lamps is paid back quickly in lower utility bills. For businesses, where most linear fluorescent lamps are used, the payback period for the most common lamps is less than two months. For households it is about a year, well within the products' useful life.

Mercury has long been recognized as a potent and persistent neurotoxin that threatens human health and the environment. Leading sources of mercury pollution in the environment are combustion of coal for power generation and improper disposal of mercury-containing products in landfills. Airborne mercury deposited on land and mercury leached from landfills eventually reaches rivers, lakes, and oceans, where it bioaccumulates in fish and shellfish. Consumption of contaminated seafood is the leading cause of human exposure to mercury. Government policies to limit mercury have often exempted fluorescent lighting—the most common use of mercury in homes and commercial buildings—because ready, mercury-free substitutes did not exist. In addition, fluorescent lamps provided energy savings compared with incandescent alternatives, and those energy savings reduced power plant mercury emissions.

The advent of cost-effective, high-quality light-emitting diodes (LEDs) completely changes the equation, making possible the elimination of mercury-containing lighting products from homes and businesses. LEDs contain no mercury and cut energy use by about half compared with fluorescent lamps, reducing power plant emissions of mercury, carbon dioxide (CO_2), and other pollutants. LED lamps are available to replace the wide variety of fluorescent lamps sold today, including most specialty varieties, such as uncommon shapes and sizes and those designed for specific commercial or industrial uses (e.g., retail or horticultural lighting). Drop-in replacements are sold for most existing light fixtures, although in some rare cases rewiring may be needed. Further, LEDs match or exceed the performance of fluorescent lighting, providing the same or higher-quality light and lasting two times longer. Table ES-1 compares key characteristics as well as upfront and operational costs and life-cycle savings for a common T8 linear fluorescent lamp (LFL) and an LED alternative in residential and commercial applications.

Table ES-1. Comparison of common T8 LFL and LED replacements

	Residential		Commercial	
Lamp type	Fluorescent	LED	Fluorescent	LED
Mercury	2.7 mg	None	2.7 mg	None
Efficacy (lumens/watt)	70–110	120–200	70–110	120–200
Color	Same	Same	Same	Same
Brightness	Same	Same	Same	Same
Typical lifetime (hours)	Up to 36,000	Up to 70,000	Up to 36,000	Up to 70,000
Price per bulb	$4.86	$6.04	$4.22	$4.76
Annual electricity cost	$2.81	$1.59	$8.82	$4.68
Life-cycle savings	—	$11	—	$27
Payback period (years)	—	1.0	—	0.1

A full transition from fluorescent lamps to LEDs would provide large mercury and CO_2 emissions reductions. Total potential cumulative reductions of mercury in lamps shipped through 2050 would be about 16,000 pounds. Another 966 pounds of mercury would be avoided cumulatively through 2050 from power plant emissions due to electricity savings. Annual carbon dioxide emissions in 2030 would drop by 18 million metric tons (MMT), an amount equal to the annual emissions of four million typical passenger cars. Total potential cumulative CO_2 emissions reductions through 2050 would be 208 million metric tons, an amount about equal to how much two coal-fired power plants would emit over that period. Figure ES-1 summarizes the environmental and economic benefits of the transition from fluorescent to LED lighting.

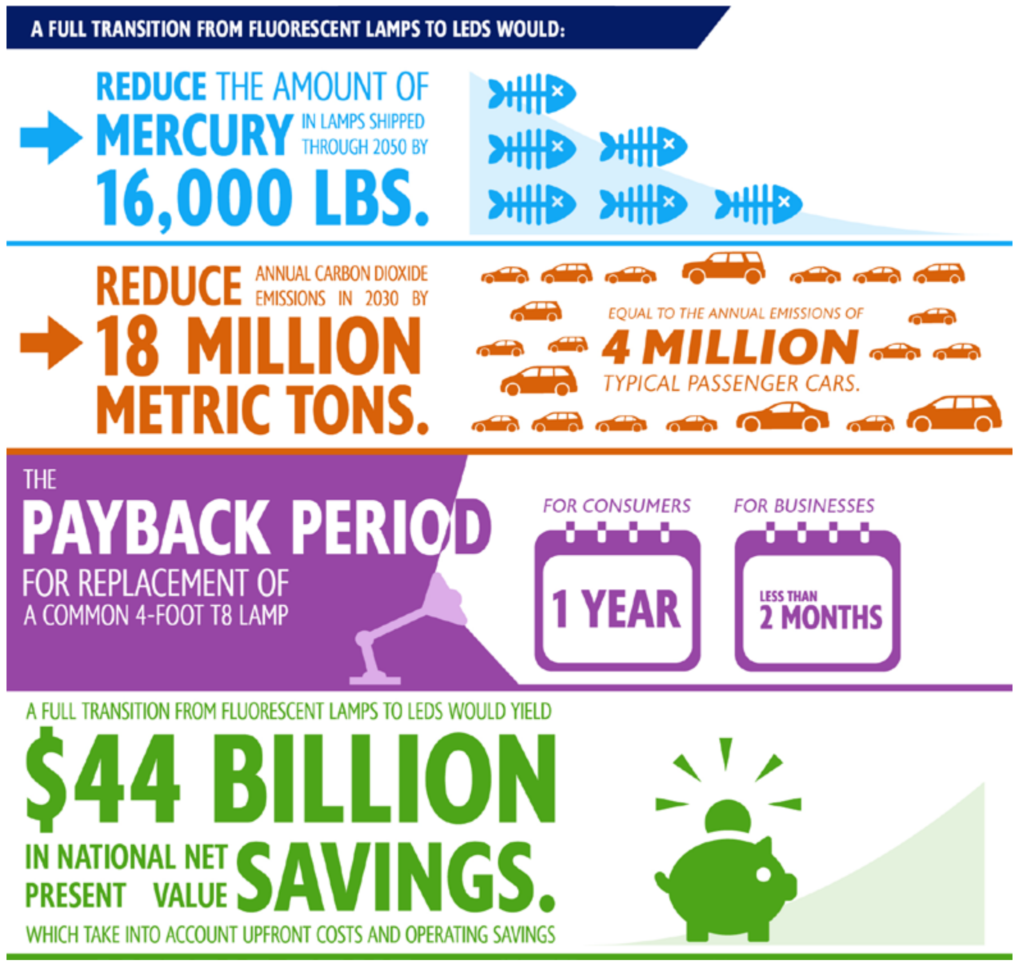


Figure ES-1. Environmental and economic benefits of transition from fluorescent to LED lighting

The transition to mercury-free LED lighting would also save businesses and households money. Average life-cycle cost savings—accounting for the upfront and operational cost differences—are positive for all of the most common lamp types. In homes, the additional upfront cost of an LED replacement for the most common fluorescent lamp, a four-foot T12, is paid back in 1.2 years; for the second most common lamp, a four-foot T8, the payback is 1 year. The payback period for the most common linear fluorescent lamp in the commercial and industrial sectors, a four-foot T8, is less than two months. For all purchasers combined, national net present value savings, which take into account upfront costs and operating savings, would be $44 billion.

States, the federal government, and international bodies have enacted policies to control sources of mercury pollution. In December 2021, the European Union (EU) eliminated all general-purpose fluorescent lighting exemptions in its Regulation of Hazardous Substances (RoHS) Directive, effectively phasing them out by 2023. The international Minamata Convention on Mercury will consider removal of fluorescent lighting product exemptions when it meets in March 2022. New efficiency standards in the EU have already eliminated some fluorescent lamps from EU markets and are set to extend to many more lamps in 2023.

As other economies move ahead of the United States to eliminate fluorescent lamps, this country risks becoming a dumping ground for banned mercury-containing lamps that suppliers cannot sell elsewhere. U.S. states and the federal government should take prompt action to update existing mercury regulations and/or adopt new mercury or lamp efficiency regulations or laws that phase out most fluorescent lighting, accelerating the transition to mercury-free, high-efficiency, lower-cost LED lighting.

Introduction

Mercury is a persistent and toxic pollutant that threatens human health and the environment. Combustion of coal and other fossil fuels in power plants and improper landfill disposal of products that contain mercury, including fluorescent lamps, are the primary sources of mercury pollution. An estimated 75% of fluorescent lamps used in the United States are not recycled or disposed of properly (Maxson, Bender, and Culver 2021). Breakage of lamps in homes, offices, and other buildings and during transport also contributes to mercury pollution in the environment. Airborne mercury deposited on land and mercury leached from landfills eventually reaches rivers, lakes, and oceans, where it bioaccumulates in fish and shellfish. Consumption of contaminated seafood is the leading cause of human exposure to mercury. Figure 1 illustrates the pathways for fluorescent lamps' releases of mercury into the environment and contamination of food and water.

To limit mercury pollution, governments have enacted policies seeking to control its sources, ranging from prohibiting the sale of certain mercury-added products to establishing requirements for end-of-life product disposal and regulating power plant emissions. However, policies have often exempted one source of mercury pollution—fluorescent lamps—due to the lack of availability of energy-efficient alternative lighting products.

The emergence of cost-effective, high-quality light-emitting diode (LED) technology means the current exemptions for fluorescent lamps are unnecessary. LED lamps, which do not contain mercury, have made remarkable progress over the past decade.[1] From 2010 to 2018, the energy efficiency of LED products doubled while dramatic cost reductions brought prices near parity with the cost of fluorescent lamps (DOE 2020a). These developments, coupled with improvements in the quality of LED light, make LEDs the smart choice for virtually all lighting applications today. With these rapid improvements in performance and declines in price, manufacturers have widened the range of LED options, and the market share for LED alternatives to fluorescent lamps has surged.

[1] In this report, we use the term *lamp* to refer to a light bulb, which includes all shapes and sizes of household light bulbs and tube or linear light bulbs such as those often used in offices. We use *light fixture* to refer to a permanent or portable device with sockets that hold lamps.

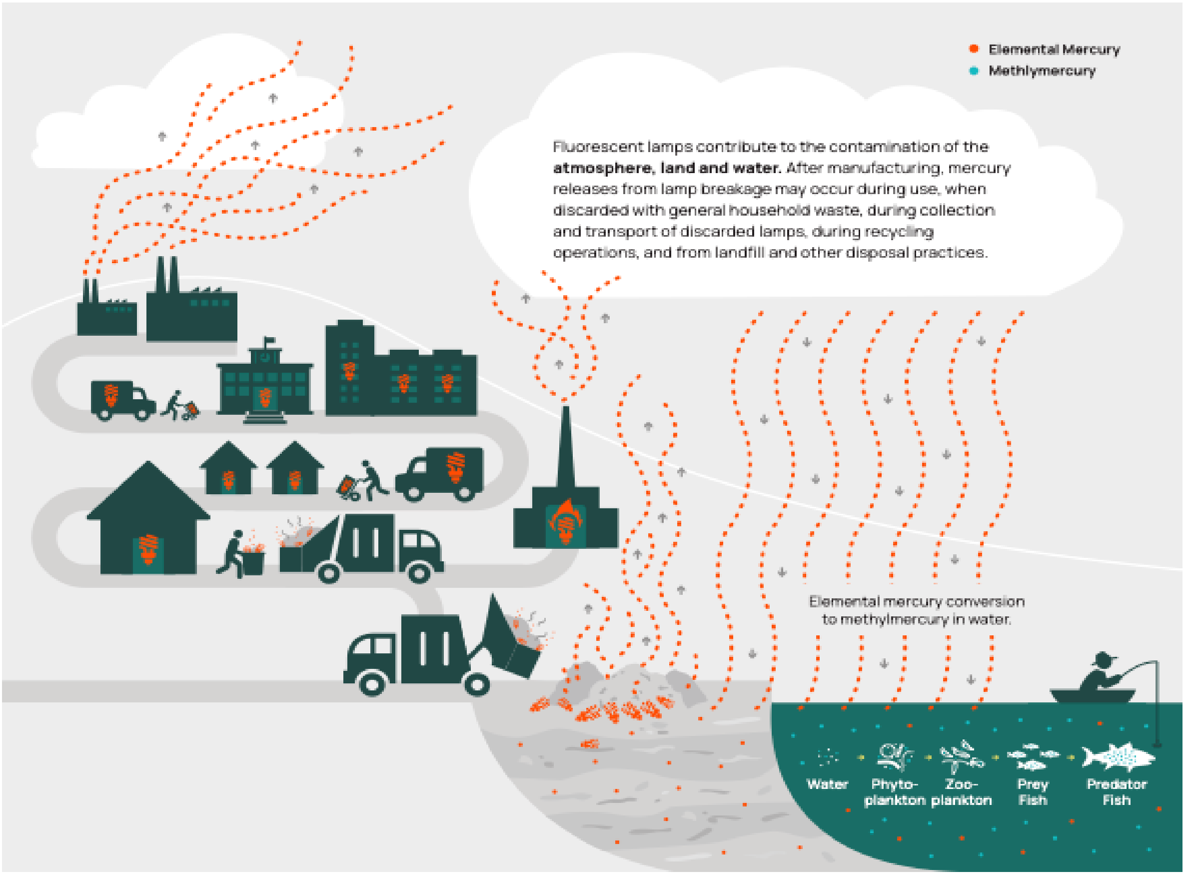


Figure 1. Fluorescent lighting releases mercury into the environment. Source: Clean Lighting Coalition/CLASP.

Widespread availability of LED lighting is good news for consumers and the environment. With today's LEDs, it is now possible to transition away from fluorescent technology to a mercury-free, energy-efficient light source. This report presents an overview and comparison of fluorescent and LED lamp types and a description of the current market for these products. We also provide a brief overview of state and federal mercury regulation and recent actions to phase out mercury lamps internationally.

Fluorescent Lamps

When electricity is applied to a fluorescent lamp, an electric arc is created in the tube, which excites mercury vapor and produces ultraviolet (UV) light. The UV activates a phosphor coating on the inside surface of the tube, which converts the UV into visible light. Figure 2 illustrates how fluorescent lamps produce light. They need mercury to work; they also need a ballast to regulate current and provide the required voltage for lamp startup and operation. The ballast may also provide

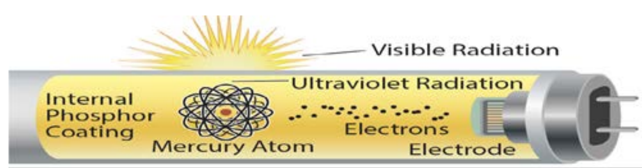


Figure 2. Illustration of process for emitting light in a fluorescent lamp. Source: IES 2020.

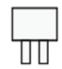
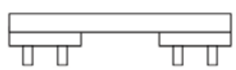
dimming control. The two main types of fluorescent lamps used in general lighting applications are linear fluorescent lamps and compact fluorescent lamps.

LINEAR FLUORESCENT LAMPS

Linear fluorescent lamps (LFLs) are the common tube-shaped lights found throughout commercial buildings and in some residential and industrial light fixtures. Common LFLs are sold in several standard tube diameters, lengths, base types, and shapes, as described in table 1. Four-foot lamps, including all diameters (T5, T8, and T12) are the most common, comprising about 85% of LFLs installed across the United States.[2]

[2] Common T5 lamps include standard-output (T5) and high-output (T5HO) lamps. T5HO lamps have the same diameter and length as standard T5 lamps but are available in higher wattages to deliver higher lumen output.

Table 1. Common linear fluorescent lamps

Shape	Base type	Tube diameter	Tube length
Straight  	Miniature bi-pin (G5) 	T5: 0.625″	6″ to 58″
	Single pin (Fa6/Fa8) 	T8: 1.0″	24″, 36″, 48″, and 96″
	Medium bi-pin (G13)  Recessed DC (R17d) 	T12: 1.5″	24″, 36″, 48″ and 96″
U-bend 	Rapid-start U-shape (2G13) 	T8: 1.0″ T12: 1.5″	2′ x 2′ with 1.625″ or 6.0″ leg spacing 2′ x 2′ with 6.0″ leg spacing

COMPACT FLUORESCENT LAMPS

Figure 3. Screw-based and pin-based CFLs

Developed in response to the oil shocks of the 1970s, compact fluorescent lamps (CFLs) were designed to serve as more energy-efficient alternatives to common incandescent lamps in general illumination applications. Common examples of CFLs are shown in figure 3.

As with LFLs, a ballast is required for CFL operation. Pin-based CFLs (also referred to as nonintegrated CFLs, or CFLni) do not contain a ballast and are designed for use with ballasted fixtures. Screw-based CFLs (integrated CFLs, or CFLi) include a ballast in the base of the lamp, allowing them to be used in conventional light fixtures with screw-in lamp (mains voltage) sockets.

CFLs come in a variety of shapes and sizes. Pin-based CFLs typically utilize T4 or T5 (½″ or ⅝″ diameter) tubes bent into single, double, or triple twin-tube shapes to achieve a compact size and the lumen output desired in the final product. Screw-based CFLs use T2, T4, or T5 and come in shapes similar to those of pin-based models, or they may be bent into more compact spirals to better fit fixtures designed for conventional incandescent lamps. Some CFLs have a clear or frosted glass or plastic covering to protect the delicate glass tube and mimic the look and shape of traditional A-lamps, globe lamps, or candelabra lamps.

Pin-based CFLs utilize a variety of base types to ensure lamp-ballast compatibility when installed in a fixture. Four-pin CFLs are designed to work with electronic ballasts including dimming ballasts. Two-pin CFLs are designed to work with magnetic ballasts and are not dimmable.

Light-Emitting Diodes

LED light sources, which do not contain mercury, work very differently from fluorescents and other common light sources. LEDs utilize semiconductor technology to convert electrical energy into visible light. Specific chemical elements are combined in layers on a chip, and when electric current flows between the layers, photons of light are emitted. The chemical composition and structure of the LED chip determine the spectrum of light emitted. Packages of one or more LED chips, electrical circuitry, and the necessary mounting are assembled for use in an LED lamp or for incorporation into an LED luminaire (i.e., a light fixture). Figure 4 shows the elements of a typical LED package and illustrates how they are incorporated into a common lamp.

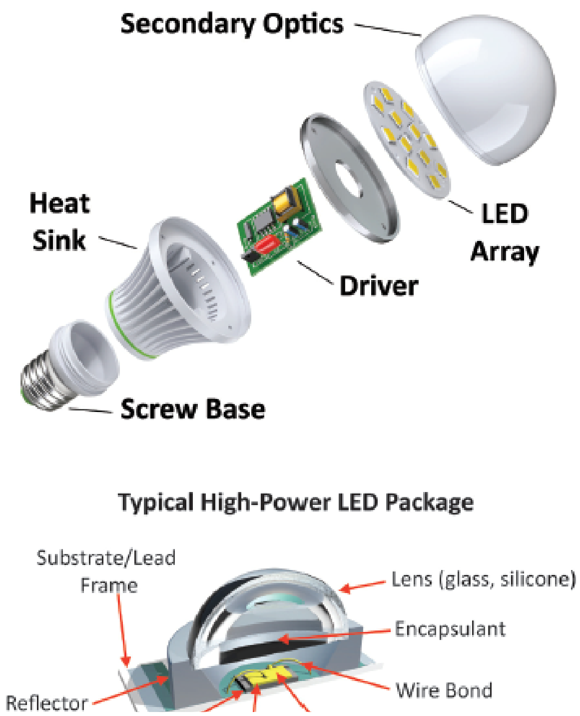


Figure 4. Elements of an LED package and typical LED lamp. Source: IES 2020.

LEDs are available for general lighting applications as well as many specialty lighting applications. LED lamps designed to serve as replacements for fluorescent lamps match the shape of LFLs and CFLs and operate in the same sockets. Compared with fluorescent lamps, LED lamps typically provide equivalent or better lighting performance with much greater energy efficiency and last two to three times longer.

LED REPLACEMENT LAMPS

LED replacements for LFL and pin-based CFLs are commonly classified as drop-in or ballast bypass lamps.[3] Figure 5 shows examples of common fluorescent lamps and their LED replacements.

- **Drop-in** (or "plug-and-play") replacement lamps are ballast driven; no rewiring is required as long as the LED is compatible with the existing ballast. These lamps may be designated as Type A, if they are solely ballast driven, or as hybrid if they are capable of operation with the existing ballast or when wired directly to line voltage.

- **Ballast bypass** lamps require rewiring of the fixture to connect the lamp directly to the electrical supply (i.e., to bypass the existing fluorescent lamp ballast). Designated as Type B, these lamps are available in single-ended, double-ended, or universal power versions for compatibility with different fixtures.

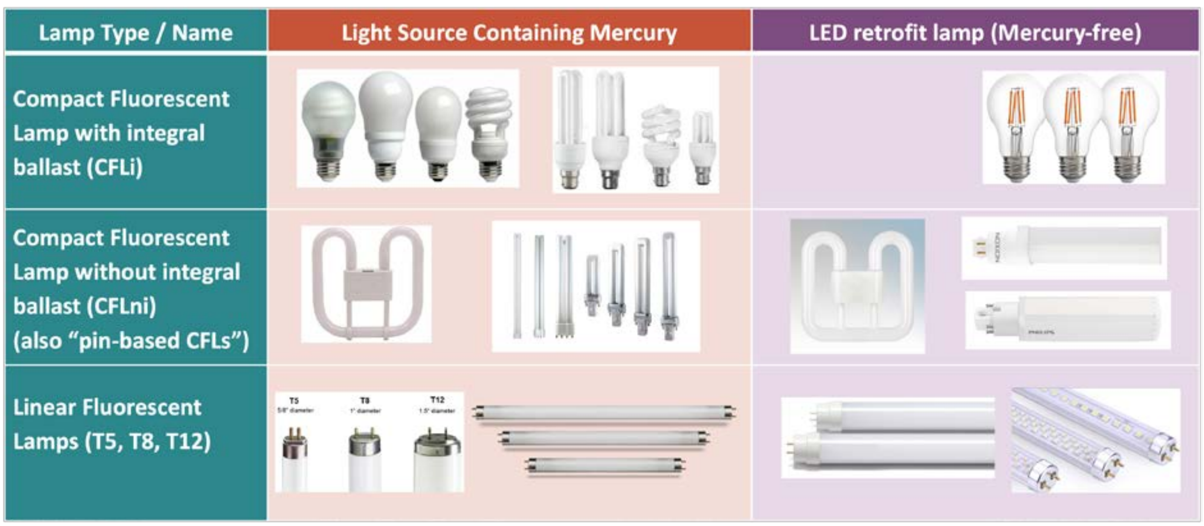


Figure 5. Common fluorescent lamps and LED replacements. Source: CLASP.

Methodology

This study addressed three questions. First, are LED lamps available to meet the range of lighting needs now met by fluorescent lamps? Second, will switching to LEDs save buyers money, and if so, how much? Third, what are the state-level and national impacts of a potential phaseout of most fluorescent lamps, including reductions in mercury and greenhouse gases and utility bill savings?

---

[3] Another type of lamp, Type C, requires fixture rewiring to replace the ballast with an external LED driver. These lamps are not simple replacements and are not covered in this report.

We addressed the first question by conducting a thorough review of LED replacements for existing fluorescent lamps. We started by developing a list of common fluorescent lamp types and their primary applications. We expanded the list by reviewing several lighting market studies, beginning with the market assessments contained in federal efficiency standards rulemaking dockets for fluorescent lamps. We also reviewed four major studies of the U.S. and European lighting markets.[4]

To identify available LED products, we searched the DesignLights Consortium (DLC) Qualified Products List (QPL).[5] This list includes only those products certified to meet specific minimum performance requirements for light output and distribution, efficacy, controllability, lumen maintenance, spectral quality, power factor, and total harmonic distortion.[6] We supplemented our review of the DLC QPL with data from manufacturer, distributor, and retailer websites. We also visited retail outlets, including national big box retailers, to assess the availability of common lamps in retail settings.

In this report, we summarize the findings from our product review, including detailed comparisons of fluorescent and LED lamps for key product characteristics and performance metrics. We also created a publicly available spreadsheet featuring a sample of widely available LED replacement lamps with key product specifications as a resource to help policymakers and their advisers easily identify LED options for a range of the most common fluorescent lighting applications.

To address the second and third questions (savings for purchasers and state and national impacts), we calculated per-unit energy savings based on input wattages for the fluorescent baseline lamps and the LED replacements and average operating hours for the residential, commercial, and industrial sectors by lamp type. We estimated per-unit incremental costs based on average prices of representative fluorescent and LED lamps from major retailers. For LED lamps, we incorporated projected price declines between 2020 and 2025 based on the U.S. Department of Energy's (DOE) solid-state lighting forecast (DOE 2019). DOE projects no significant further price declines after 2025.

---

[4] Major market studies reviewed for this report include *2015 U.S. Lighting Market Characterization* (DOE 2017a), *Adoption of Light-Emitting Diodes in Common Lighting Applications* (DOE 2020b), *Energy Savings Forecast of Solid-State Lighting in General Illumination Applications* (DOE 2019), and *Assessing Annex III Fluorescent Lamp Exemptions in the Light of Scientific and Technical Progress* (Bennich and Scholand 2020).

[5] The DLC is a nonprofit organization that works with the lighting industry, utilities, energy efficiency programs, building owners, and government agencies to develop certification criteria for high-performance, energy-efficient commercial lighting products. The DLC maintains a searchable database of all products certified to meet its performance criteria, including more than 30,000 LED replacement lamps.

[6] Full details of the latest DLC technical requirements are in the Technical Requirements Tables Version 5.1.

We analyzed lamp compatibility tables published by eight major lighting suppliers (see text box below). On the basis of this analysis, we concluded that 100% of T12 LFLs, 93% of T8 LFLs, and 92% of T5 LFLs could be replaced with drop-in LEDs. We assumed the remaining lamps in these categories would be replaced with ballast-bypass LEDs. Finally, for pin-based CFLs, we assumed that 100% of lamps could be replaced with a drop-in LED. For ballast-bypass linear LEDs, we incorporated the additional cost of a fuse kit, which protects the installer if a fluorescent lamp is reinstalled in the future. We also incorporated the additional labor cost to rewire the fixture to bypass the existing fluorescent ballast for ballast-bypass linear LEDs. On the basis of these inputs, we estimated the savings for purchasers switching from fluorescent to LED lamps.

For our life-cycle cost analysis, we used the lifetime of the baseline fluorescent lamp for the analysis period. However, to reflect the longer lifetimes of LEDs compared with fluorescent lamps, we incorporated a residual value for the LED lamp that represents its remaining value at the end of the fluorescent lamp's lifetime. We calculated the simple payback period as the additional upfront cost divided by the first-year electricity bill savings.

For state- and national-level savings, we estimated savings through 2050 from a policy that would phase out LFLs and CFLs in 2023. For LFLs, we estimated annual shipments based on historical shipment data and data on the recent market penetration of LEDs in the linear lamp market. We assumed that recent trends in declining LFL sales would accelerate. Specifically, we assumed that the annual rate of decline in shipments of LFLs would reach 11% by 2030, then increase to 20% and remain constant at that rate through 2050. For pin-based CFLs, we estimated annual shipments based on the stock of lamps in 2015 and average lifetimes and assumed that the annual rates of decline would be equivalent to those of four-foot T8 lamps. We did not estimate any savings for screw-base CFLs, since their market share is now less than 2% and we expect it will be close to zero by 2023.

Manufacturer Ballast Compatibility Tables

GE Lighting
Philips
Sylvania
Feit Electric
Technical Consumer Products (TCP)
Universal Lighting Technologies
EiKO
Great Value

We estimated the mercury content of each fluorescent lamp by averaging the reported mercury content from Philips, GE, and Sylvania lamps. Table 2 shows our assumptions for mercury content per lamp.

Table 2. Mercury content per lamp

	Mercury content per lamp (mg)			
Baseline lamp type	Philips	GE	Sylvania	Average
4-foot T12 – 40 W	4.4	9.0	7.5	7.0
4-foot T12 – 34 W	4.4	5.0	7.5	5.6
4-foot T8	1.7	3.0	3.5	2.7
4-foot T5	1.4	2.5	1.8	1.9
4-foot T5 high output	1.4	2.5	2.5	2.1
8-foot T12	6.8	6.8	7.5	7.0
8-foot T12 high output	6.8	6.8	8.4	7.3
8-foot T8	4.4	4.4	8.5	5.8
8-foot T8 high output	4.4	3.5	8.5	5.5
Pin-based CFL	1.4	1.3	1.3	1.3

We calculated state-by-state electricity savings and costs by allocating national lamp sales to each state. For residential lamp sales, we allocated according to the number of households; for commercial and industrial lamps, we used data on lighting electricity use. We determined state-level CO_2 emissions reductions from electricity savings using state-by-state projected average power plant emissions rates through 2050. Because fossil fuel power plants, particularly coal-fired plants, produce mercury emissions, we also calculated the mercury emissions reductions from reduced electricity production. We evaluated electricity bill savings using projected state-by-state electricity prices for the residential, commercial, and industrial sectors.

We calculated net present value savings as the difference between the present value of the total electricity bill savings from products sold through 2050 and the present value of the total estimated additional costs. We discounted future costs and savings to 2021 using a real discount rate of 5%. Finally, we determined benefit–cost ratio by dividing the present value of savings by the present value of costs.

Appendix C contains details of our methodology and assumptions.

Market Assessment

LEDs make up a growing share of the U.S. lighting market; however, LFLs and pin-based CFLs continue to account for a large proportion of lamp sales. In this section, we assess the current market for fluorescent and LED lamps to 1) identify the primary applications for LFLs and pin-based CFLs in the residential, commercial, and industrial sectors; 2) assess the availability of LED replacement lamps for these applications; and 3) compare fluorescent and

LED replacement lamp performance in terms of energy efficiency, light quality, lifetime, and other characteristics. We find that high-quality, low-cost LED lamps are available to replace fluorescent lamps in all of the most common fluorescent lamp applications and most specialty lamp applications. Table 3 provides a comparison of key characteristics of a common LFL and its LED alternative and the dollar savings from switching from one LFL to an LED.

Table 3. Comparison of common LFL and LED replacement*

	Residential		Commercial	
Lamp type	Fluorescent	LED	Fluorescent	LED
Mercury	2.7 mg	None	2.7 mg	None
Efficacy (lumens/watt)	70–110	120–200	70–110	120–200
Color	Same	Same	Same	Same
Brightness	Same	Same	Same	Same
Typical lifetime (hours)	Up to 36,000	Up to 70,000	Up to 36,000	Up to 70,000
Price per bulb	$4.86	$6.04	$4.22	$4.76
Annual bill cost	$2.81	$1.59	$8.82	$4.68
Life-cycle savings	—	$11	—	$27
Payback period (years)	—	1.0	—	0.1

*** Data for four-foot T8 linear products are used for comparison.**

MARKET DESCRIPTION

LINEAR LAMPS

LFLs are most common in commercial buildings, where they have historically been used for office and other general lighting needs. In homes, linear lamps have most frequently been used in kitchens as well as basement and garage applications. According to the *2015 Lighting Market Characterization*, more than 2.3 billion LFLs were in use in the United States in 2015 (DOE 2017a). Of these, 69% were used in commercial buildings, 22% in homes, 7% in industrial facilities, and the remaining 2% in outdoor applications. Four-foot lamps of all diameters (T5, T8, and T12) are by far the most common lamp type, accounting for 84% of installed lamps in 2015.

In homes, four-foot T8s and T12s are the most popular lamp types, making up about 40% and 50% of installations, respectively, in 2015. In commercial buildings, four-foot T8s are by far the most common lamp type, accounting for more than 70% of installed lamps. They are also the most popular lamp type in industrial applications. Table 4 shows the distribution of LFLs by sector, with sector percentages shown in bold type for the most common installations (i.e., those accounting for more than 5% of installed lamps).

Table 4. Distribution of installed LFL lamps by end-use sector

	Residential	Commercial	Industrial	All sectors
T5 (all)	3.5%	**5.7%**	**19.8%**	**6.0%**
T8 < 4-foot	0.2%	1.2%	0.3%	0.9%
T8 4-foot	**40.5%**	**70.9%**	**56.5%**	**61.6%**
T8 > 4-foot	1.1%	1.0%	**7.7%**	1.5%
T8 U-shaped	0.0%	2.2%	0.3%	1.5%
T12 < 4-foot	0.3%	0.1%	0.0%	0.1%
T12 4-foot	**49.8%**	**16.5%**	**7.7%**	**22.8%**
T12 > 4-foot	4.1%	1.5%	**6.6%**	2.4%
Miscellaneous*	0.4%	0.4%	1.0%	2.8%

*** Outdoor lighting makes up a negligible quantity of miscellaneous LFLs. Source: DOE 2017a.**

Overall shipments and market penetration of LEDs have grown significantly since publication of the 2015 lighting market characterization; however, LFLs continue to dominate the market, with 69% of linear lamp shipments in the third quarter of 2021 versus 31% for tubular LEDs (TLEDs) (NEMA 2021b). Figure 6 shows the change in market penetration for LFLs and TLEDs based on shipment data collected by the National Electrical Manufacturers Association (NEMA). Research in California and the Pacific Northwest shows that TLEDs are now installed in almost all new construction and lighting retrofit projects and suggests that the majority of ongoing LFL sales serve the lamp replacement market (TRC 2019). A substantial market opportunity remains for TLED replacement lamps in existing buildings.

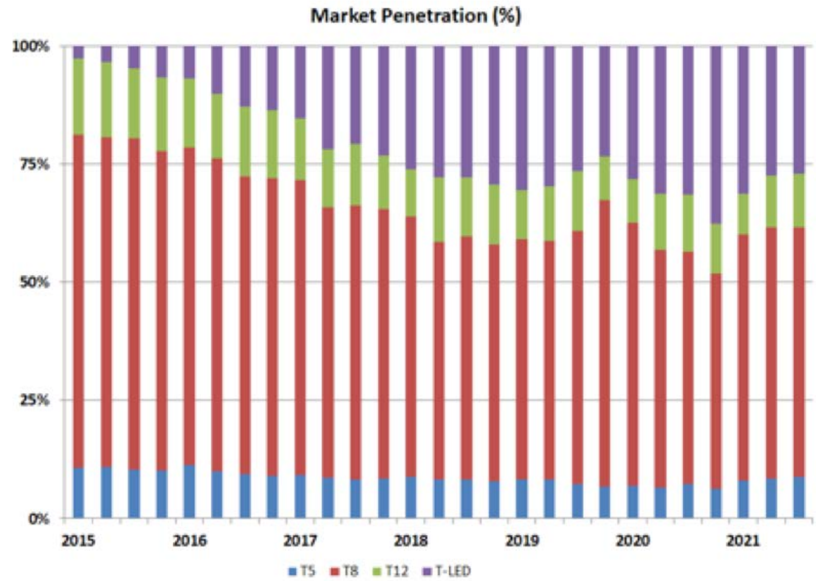


Figure 6. Market penetration of linear fluorescent and TLED lamps through Q3 2021. Source: NEMA 2021b.

Compact Fluorescent Lamps

A similar number of CFLs were in use in 2015—a total of 2.2 billion (DOE 2017a). Ninety-two percent of CFLs were used in homes and 7% in commercial buildings. Industrial facilities and outdoor applications accounted for less than 1% of CFL installations. More than 83% of installed CFLs (more than 1.8 billion) were general-service screw-based CFLs, which are very easy to replace with screw-based LEDs.[7] Since 2015, screw-based CFL sales have plummeted in favor of LEDs and now account for less than 1% of the consumer market for A-line lamps (the ubiquitous pear-shaped bulbs), while LEDs account for 76.8% and halogens 22.5% (NEMA 2021a).

General-service pin-based CFLs were much less common than general-service screw-based CFLs in 2015, representing just 5% of CFL inventory. Pin-based lamps accounted for the largest share of CFLs in the commercial sector, totaling more than 80 million lamps. Another 30 million pin-based CFLs were installed in homes. Pin-based LED replacement lamps are a simple drop-in alternative to CFLs and provide an opportunity to accelerate the full transition away from CFLs and eliminate the mercury associated with these lamps. Table 5 summarizes the distribution of CFLs by sector.

[7] In addition to general-service screw-based CFLs, more than 184.5 million CFL reflector lamps were installed in 2015. Most CFL reflector lamps utilize a screw base and are easily replaced with LED reflector lamps.

Table 5. Distribution of installed CFL lamps by end-use sector

	Residential	Commercial	Industrial	All sectors
General service, pin	1.5%	**48.5%**	**45.0%**	4.9%
General service, screw	**87.7%**	**38.3%**	8.8%	**83.6%**
Reflector	8.6%	3.6%	**29.3%**	8.2%
Miscellaneous*	2.2%	9.6%	16.9%	3.2%

*** Outdoor lighting makes up a negligible quantify of miscellaneous CFLs. Source: DOE 2017a.**

LED REPLACEMENT LAMP AVAILABILITY

LED replacement lamps are widely available at retail outlets, including national home improvement stores (e.g., Home Depot and Lowe's), local hardware stores, electric supply houses that serve the commercial market (e.g., Grainger), and lighting websites (e.g., 1000bulbs.com and bulbs.com). The DLC Qualified Products List contains more than 30,000 LED replacements for LFLs and four-pin CFLs. While the DLC QPL is the largest list of verified high-performance LED products in the United States, it is not an exhaustive list of all LED products on the market, since it includes only those certified to meet the DLC technical requirements. Because we use the QPL for our analysis, our findings represent a conservative estimate of the number of LED products available to replace existing fluorescent lamps.

Manufacturers on LED compatibility and performance

GE Lighting "All-purpose. All energy efficient. Our range of general purpose LED bulbs are your dimmable, long-lasting, energy efficient solution to nearly every fixture in your home." "Long life. Less hassle. With full instant brightness and no flicker, our energy efficient LED Tubes provide a long-lasting, high-quality light to high fixtures."

Philips "Simple retrofit solutions with spectacular energy savings. Comprehensive retrofit InstantFit, MainsFit and FlexFit portfolios enabling hassle-free installation for all of your linear application needs."

Sylvania "Engineered to operate on existing instant start and select programmed rapid start electronic T8 ballasts, these lamps minimize labor and recycling costs…the SubstiTUBE IPS LED T8 is not affected by switching cycles, the use of occupancy or vacancy sensors can be installed with the existing instant start ballasts for optimal energy savings."

Espen "The upgrade to LED technology is as simple as replacing the old fluorescent lamps with new Retroflex lamps. This saves you up to 50% of system power while maintaining or increasing illumination levels. These lamps work directly off your existing electronic ballasts, within your fixtures, and come in a range of shapes and sizes."

> Topstar "Topstar ballast compatible LED T8 lamps are an ideal energy savings choice for existing linear fluorescent fixtures."

For our analysis of the DLC QPL, we excluded products that were added to the list prior to January 1, 2019. With the rapid pace of improvement in LED technology, newer products are a better representation of the current LED lighting market. We also excluded Type C products, which require a fixture-mounted LED driver external to the lamp. This left us with a total of 7,645 LED replacement lamps for various applications. The DLC QPL includes more than 230 brands of linear lamp replacements from 188 manufacturers and 37 brands of pin-based CFLs from 37 manufacturers. The DLC QPL does not include two-pin CFLs or many four-pin CFL base types—only 2G11 and G24Q/GX24Q base lamps are listed. We supplemented data from the DLC with information from retailer websites to expand the coverage of CFLs in our analysis, bringing the total number of models to 7,729. Table 6 summarizes the number of models by lamp type.

Table 6. LED lamps listed in the DLC database since January 2019, by type

Linear replacement lamps		Pin-based replacements for CFLs	
Lamp type	Number of listed products	Lamp base type	Number of listed products
4-foot T5	275	2G11	125
4-foot T5HO	295	G24Q/GX24Q	179
2-foot T8	633	G24D/GX24D*	40
3-foot T8	409	G23/GX23*	42
4-foot T8	4,858	2G7/2GX7*	2
8-foot T8	577		
U-bend	294		
TOTAL	7,341	TOTAL	388

*** These base types are not included in the DLC database. Information on these were collected from online lighting retailers 1000bulbs.com and bulbs.com.**

Of the linear replacement lamps in the data set analyzed, 40% (n=2,924) are ballast-compatible drop-in replacements, of which about half (n=1,484) are hybrid products that work with or without ballasts; 60% (n=4,417) are ballast bypass (Type B). Of the pin-based CFL replacements, 68% (n=264) are drop-in and 32% (n=124) are ballast bypass. Table 7 shows a detailed breakdown.

Table 7. DLC QPL product distribution by type

Lamp type	Drop-in (Type A and hybrid)		Ballast bypass (Type B)	
	n	*% of lamp type*	*n*	*% of lamp type*
Linear replacement lamps				
T5 4-foot	62	22%	213	78%
T5HO 4-foot	121	41%	174	59%
T8 2-foot	303	48%	330	52%
T8 3-foot	193	47%	216	53%
T8 4-foot	1,987	41%	2,871	59%
T8 8-foot	51	9%	526	91%
U-bend	207	70%	87	30%
TOTAL / % of all LFLs	2,924	40%	4,417	60%
Pin-based replacements for CFLs				
2G11	40	32%	85	68%
G24Q/GX24Q*	179	100%	0	0%
G24D/GX24D**	14	35%	26	65%
G23/GX23**	31	74%	11	26%
2G7/2GX7**	0	0%	2	100%
TOTAL / % of all CFLs	264	68%	124	32%

*** Among pin-based replacement LEDs, the DLC QPL only includes 2G11 and four-pin Type A G24Q/GX24Q lamps. Additional two- and four-pin Type B and hybrid lamps with this base type are available. ** These base types are not included in the DLC database. Information on these were collected from online lighting retailers 1000bulbs.com and bulbs.com.**

Sample LED Replacements

We searched retailer and manufacturer websites to compile a list of LED replacement lamps. The list includes key technical specifications, direct links to retailer/manufacturer websites, and pricing information. To view this sample of LED lamps, please refer here.

BALLAST COMPATIBILITY

As described above, fluorescent lamps require a ballast to operate, and a drop-in LED needs to be compatible with an installed ballast to function in an existing light fixture. To make it easy for users to convert to LED, drop-in TLEDs from major manufacturers are designed for compatibility with existing fluorescent ballasts. For example, Philips reports that its InstantFit lamps work with more than 350 ballasts and drivers (see figure 7). Manufacturers publish lamp compatibility tables to help purchasers identify products that will work with the ballasts in their existing fixtures.

Figure 7. Promotional material for Philips InstantFit LED lamps. Source: Signify 2021a.

Using ballast compatibility tables from eight companies, we compiled a database of 897 LFL ballasts and identified which of the eight lamp manufacturers included in our review reported products compatible with each ballast. We found that for 836 (93.2%) of the ballasts listed, there were compatible lamps from at least one manufacturer. Many of the ballasts were compatible with lamps from multiple manufacturers. Table 8 summarizes ballast compatibility by lamp type.

We also compiled compatibility data on 127 CFL ballasts from three leading LED replacement lamp manufacturers (Philips, Sylvania, and TCP). Our review found that 100% of the ballasts listed were compatible with lamps from one or more of those three lamp manufacturers.

Table 8. Ballast compatibility for linear and compact fluorescent lamps

Lamp type	Ballasts (n)	Compatibility
Linear fluorescent lamps		
T5	143	92.3%
T8	685	92.7%
T12	69	100%
Overall	897	93.2%
Compact fluorescent lamps		
Pin-based	127	100%

The data show that drop-in LED replacements are widely available today for existing fluorescent lamp fixtures. In the infrequent instances when they are not, a simple fixture rewiring can be completed to accommodate ballast-bypass LEDs.

PRODUCT PERFORMANCE: FLUORESCENTS VERSUS LEDS

Today's LED lamps provide performance comparable to, and in many ways superior to, that of the LFLs and CFLs they are designed to replace—while also containing no mercury. LEDs span a wide range of technical specifications to suit purchaser needs. The following sections compare key performance characteristics LED replacements with those of the most common types of LFLs and pin-based CFLs. We assess light output and energy efficiency, light quality as measured by color temperature and color rendering index, and product lifetime.

Data on fluorescent product characteristics were collected from manufacturer spec sheets and retail websites. LED performance data are based on products certified to meet DLC technical requirements.

We find that LEDs provide the same amount of useful light as a typical fluorescent lamp while consuming about half as much electricity. Available LEDs provide the same range of light qualities provided by fluorescent lamps with respect to color temperature (warm white to cool white to daylight) and color rendering. LEDs exhibit better dimming performance, and some products even allow for color tuning, which enables the user to change the light temperature as desired. LEDs are available with product lifetimes of up to 70,000 hours for TLEDs and 36,000 hours for CFL replacements. The International Electrotechnical Commission has issued safety standards for both self-ballasted LED lamps and linear replacement lamps (IEC 62560:2011 and IEC 62776:2014, respectively). Underwriters Laboratories (UL) and Electrical Testing Laboratories (ETL) test LED lamps to national safety standards. Tested and approved lamps may carry the UL or ETL mark.

In this section we discuss details of our findings on the performance of LED replacements relative to linear and compact fluorescent lamps.

LED Replacements for Linear Fluorescent Lamps

Light Output, Wattage, and Efficacy (LFLs)

Today's LED linear replacement lamps offer light output comparable to that of LFLs while typically consuming roughly half the energy, resulting in a significant improvement in lamp efficacy. DOE projects a further improvement of 50% in LED efficiency by 2035 (DOE 2020a).

High Performance LED replacements for conventional T5 lamps

T5

Philips T5 LED tubes offer an affordable, energy saving retrofit solution. The T5 lamps have been engineered to withstand the test of time with a 50,000-hour lifetime and a limited 5-year warranty to back it up. The lighting performance effectively replaces conventional fluorescent T5 HO or T5 HE lamps. Available in either InstantFit (Type A or Type C) or MainsFit (Type B / Ballast bypass), Philips T5 TLEDs provide a variety of options for any application.

Order Code	Full Product Name	Luminous Flux (Nom)
476473	11T5HE/34-840/IF15/G/DIM 10/1	1500 lm
476481	11T5HE/34-850/IF15/G/DIM 10/1	1500 lm
476499	14T5HE/46-830/IF20/G/DIM 10/1	2000 lm
476507	14T5HE/46-835/IF20/G/DIM 10/1	2000 lm
476515	14T5HE/46-840/IF21/G/DIM 10/1	2100 lm
476523	14T5HE/46-850/IF21/G/DIM 10/1	2100 lm

Figure 8. Philips Lighting spec sheet for T5 LED replacement lamps. Source: Signify 2021b.

LEDs are directional light sources, capable of delivering more of the light emitted from the lamp to a room or targeted area than fluorescents can. Fluorescent lamps are diffuse light sources that require optical components in the light fixture to direct light out. The efficiency of the fixture affects how much of the light emitted from the lamp is delivered to the targeted area. The difference in directionality allows an LED lamp to deliver the same amount of useful light into a room with 25–30% fewer lumens than the fluorescent lamp it is replacing. As illustrated in figure 8, Philips states that its 2000- and 2100-lumen LEDs' "lighting performance effectively replaces conventional fluorescent T5 lamps," which emit 2900 lumens.

Table 9 compares light output, wattage, and efficacy for a sample of common LFLs and TLED replacement lamps. As noted, LEDs provide more usable light per lumen output when retrofitted into fluorescent fixtures, so LEDs offering equivalent illumination of a room can have lower overall light output. TLED examples in table 9 are effective replacements for LFLs, providing comparable useful light with lower lumen output ratings and about half the wattage. Savings from replacing a T12 with a TLED are even greater.

Table 9. Light output, wattage, and efficacy of a sample of available LFLs and TLEDs

Lamp	Light output (lumens)	Wattage (W)	Efficacy (lumens/W)
Linear fluorescent lamps			
T5 – Ushio Cool White T5	2900	28	103.6
T5HO – Philips High Output T5	5000	54	92.6
T8 – Sylvania 22439 – FO32/V50/ECO	2450	32	75.6
T12 – Philips Neutral White T12	2550	40	63.8
LED replacement lamps			
T5 – Philips T5 LED Bulb	2100	14	150
T5HO – Feit 54W Equivalent Cool White	3300	25	132
T8* – TCP 4 ft. LED T8 Tube	2400	18	133.3
T8* – PLT 4 ft. LED T8	2200	14	157.1

***T8 LED lamps are designed to work as T8 and T12 replacements.**

LIGHT QUALITY (LFLS)

Light color and the ability of a lamp to accurately render the color of the surfaces lit are two key characteristics of light quality. Light color (technically known as correlated color temperature, or CCT) is measured in kelvins (K). Lamps on the lower end of the CCT range emit warmer light with orange or yellow tones, often marketed as “warm white” or “soft white” (2500–3500 K). At the higher end of the range—above 4500 K—lamps emit a cooler, blue light sometimes characterized as “daylight,” because these color temperatures mimic the blue-white of daylight, or as “bright white.” Mid-range color temperatures of 3500–4500 K emit a more “neutral white” or “cool white” light.[8] Figure 9 shows the number of linear LED

[8] This terminology is used by manufacturers and retailers in their marketing and therefore is more useful and familiar to consumers. The “correct” technical spectrum places “warm white” below 3500 K, “neutral white” at 3500–5000 K, “cool white” at 5000–6500K, and “daylight” at 6500 K and above.

replacement lamps from the DLC QPL for each of these three color temperature classifications. LED replacement lamps are available in the same common range of correlated color temperatures (2500–6500 K) as conventional LFLs for residential, commercial, and industrial applications.

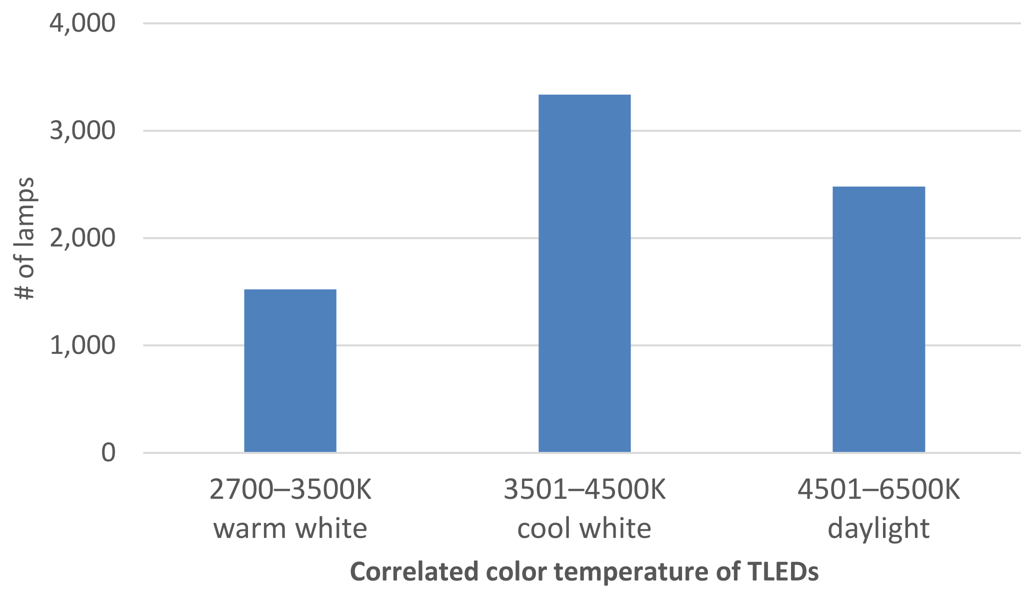


Figure 9. Number of LED linear replacement lamps grouped by color temperature classifications

Color rendering index (CRI) is a measurement of how accurately a light source illuminates the color of objects in the lit space, reported on a scale of 0 to 100. The typical CRI for conventional fluorescent lamps is 80 to 85, with most reporting a nominal CRI value of 82. Lamps with a CRI greater than 87 are classified as high-CRI lamps.[9] For general-purpose lighting, lamps with mid-range CRIs are commonly used. High-CRI lamps are used in applications where true color is important, such as in cinematography, retail displays of produce and jewelry, and neonatal care. Most high-CRI linear fluorescents report CRIs no higher than 95, but some products report values as high as 98.

LED replacement lamps on the DLC QPL have CRIs ranging from 80 to 90, including 32 rated as high-CRI lamps. For specialty applications where very high CRI is desired, the QPL includes 170 Type C lamps with CRI ranging from 90 to 97. Through a search of retail websites we

[9] Federal law enacted in 1992 exempted high-CRI fluorescent lamps from federal efficiency standards because achieving high CRI and high efficiency is difficult, and at the time, high-CRI lamps were an expensive niche product. Subsequently, manufacturers developed low-cost, high-CRI lamps as a means to circumvent federal efficiency requirements.

were able to identify other drop-in replacement lamps with CRIs of 95 to 98. Table 10 provides CRI values for a sample of LFLs and TLEDs.

Table 10. CRI of a sample of available LFLs and TLEDs

Lamp	CRI
Linear fluorescent lamps	
PLT F54T5/840/HO – High Output T5	80
Sylvania 32W T8	90
Philips 32W 48in T8 Bright White	98
LED replacement lamps	
PLT 25W 4 ft. LED T5HO	83
Sylvania 13W 4-Foot T8 LED Dimmable	90
NorthLux 18W 4ft T8 LED Tube	95
Yujileds 18W Full Spectrum T8 LED Tube	98

Lifetime and Warranty (LFLs)

LED lighting products are distinguished from fluorescent light sources by much longer lifetimes, typically about two times longer than fluorescent, although LEDs with even longer lives are available. Longer-lived products can provide additional maintenance costs savings, which is especially helpful in hard-to-reach locations. All products on the DLC QPL must meet a minimum lifetime requirement of 50,000 hours and a minimum warranty period of five years. The QPL does not include lifetime data for all listed products; however, most products with lifetime data report 50,000 hours. For commercial buildings, this corresponds to 16.9 years of operation at the daily average usage for LFLs of 8.1 hours (DOE 2017a). Some products report lifetimes as high as 70,000 hours. In contrast, common LFLs report lifetimes of 24,000 to 30,000 hours (roughly 8–10 years) with typical warranties of 36 months. Table 11 compares the lifetimes and warranties of specific LFL and LED products.

Table 1. Lifetime and warranty comparison for T8, T5, and T5HO lamps

	Linear fluorescent lamps			LED replacement lamps		
T8		Philips Advantage 841 32W Cool White | 4 ft.	30,000 hours, 3-year warranty		Philips LED InstantFit 14W Cool White | 4 ft.	50,000 hours, 5-year warranty
T5		Ushio 28W Cool White Fluorescent Tube | 4 ft.	24,000 hours, No warranty		TopStar LED 15W T5HE 3000K–5000K | 4 ft.	50,000 hours, 5-year warranty
T5HO		PLT 54W 850 Bright White | 4 ft.	24,000 hours, No warranty		RAB Lighting 25W 850 Bright White Glass Tube | 4 ft.	50,000 hours, 5-year warranty

The T8 fluorescent lamp is rated for 30,000 hours, and both T5 fluorescents are rated for 24,000 hours, while the T8 LED and both T5 LEDs are rated for 50,000 hours. This means the LEDs have 1.7 to 2 times longer lifetimes. Warranty coverage on the two different lamp technologies is markedly different as well: While the LED lamps have five-year warranties, only one fluorescent lamp offers a three-year warranty and the other two fluorescents offer none at all. From both a rated lifetime and a warranty perspective, it is safe to conclude that the LED direct retrofits for fluorescent T8 and T5 lamps are superior substitutes.

LED Replacements for Pin-Based CFLs

LEDs offer consumers a wide range of benefits relative to CFL lamps. Consumer preference for LEDs is demonstrated by the significant uptake of screw-based LEDs, which have all but supplanted screw-based CFLs in the market. Given the success of LEDs, several leading manufacturers have stopped making screw-based CFLs, and many retailers have stopped carrying or severely reduced their stock of CFL products.

The market for pin-based CFLs—the majority of which are used in the commercial sector—has been slower to shift to LEDs. Because this market is less than 10% the size of the screw-based CFL market, manufacturers and retailers have focused on the latter instead. However, as with LFLs, LED drop-in pin-based lamps are widely available, cut energy use in half relative to the fluorescent lamps they replace, provide the same or better-quality light, and last two and a half to five times longer.

The DLC QPL provides data on more than 300 four-pin LED replacements for CFLs with either 2G11 or G24Q/GX24Q base types (the G24Q/GX24Q base types are listed as horizontally or vertically mounted lamps). Lamps with a 2G11 base have a long, single twin tube with four pins lined up in a row. Known as PLL, Biax L, Lynx L, and Dulux L lamps, these are often used in commercial applications including 2x2 recessed fixtures, pendant fixtures, cove and wall wash lighting, wall sconces, signage, and landscape lighting. Figure 10 shows both common base types.

Figure 10. 2G11 (left) and G24Q (right) base types for CFL and LED replacement lamps

Light Output, Wattage, and Efficacy (CFLs)

Table 12 provides a comparison of CFL and LED replacement lamp light output, wattage, and efficacy. QPL data are supplemented with information from manufacturer spec sheets and retailer websites for CFLs and other LED replacement lamp categories. As with LED replacements for LFLs, the replacements for CFLs provide the same lighting with lower rated lumen output and much lower input watts. Electricity consumption is reduced by more than half when using LEDs instead of CFLs.

Table 12. Light output, wattage, and efficacy of a sample of available CFLs and TLEDs

Lamp	Light output (lumens)	Wattage (W)	Efficacy (lumens/W)
Compact fluorescent lamps			
2-pin – Sylvania GX23 Soft White Single Twin Tube	800	13	61.5
4-pin – Philips 2G11 Cool White Single Twin Tube	2970	40	74.3
4-pin – Sylvania 2G11 Bright White Single Twin Tube	2709	40	67.7
LED replacement lamps			
2-pin – Green Creative 3000K GX23 Hybrid LED	500	5.5	90.9
4-pin – Philips 4000K Single Twin Tube	2300	16.5	139.4
4-pin – Sunlite FT/LED/IS/17W/50K Super White	2645	17	155.6

Light Quality (CFLs)

Light color and the ability of a lamp to accurately render the color of the illuminated surfaces are two key characteristics of light quality. As discussed for linear lamps, both CCT and CRI are useful measures of light quality. Pin-based LED replacement lamps are available in the same range of CCT (2500–6500 K) as LFLs. Figure 11 shows the number of four-pin CFL replacement lamps from the DLC QPL for each of the three common color temperature classifications.

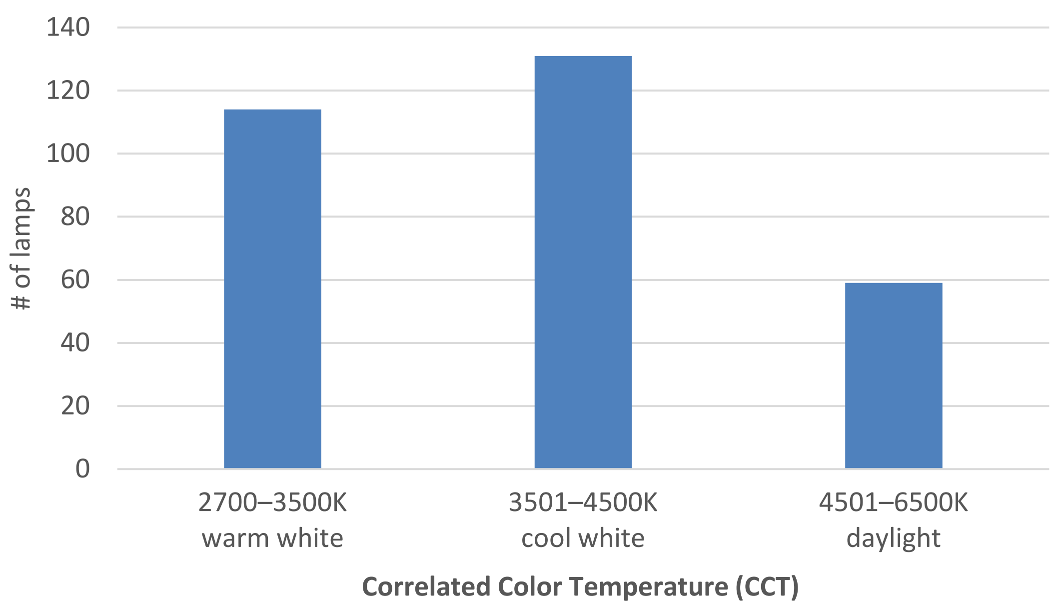


Figure 11. LED replacements for CFLs by color temperature

Four-pin LED replacements on the DLC QPL have CRIs ranging from 80 to 85. A review of manufacturer product literature and retailer websites finds that almost all two- and four-pin CFLs have a CRI of 82.

Specialty lamps for the film and TV industry are the only high-CRI CFLs we identified. These are relatively high wattage (50–55 W) lamps with 2G11 bases designed to meet the specific CRI and color temperature requirements of film (5000–5600 K) and TV (3000–3200 K) production. Most of these lamps have CRIs of 89–91. GE also produces versions with CRIs of 92 and 95, but these models have a much lower rated lifetime—2,000 hours versus 10,000 to 20,000 hours for similar products.

LIFETIME AND WARRANTY (CFLS)

All four-pin base products on the DLC QPL must meet a minimum lifetime requirement of 50,000 hours and a minimum warranty period of five years. As with LFL replacements, the QPL does not include lifetime data for all listed products. Most LED products with lifetime data report 50,000 hours, equivalent to 11 years at the average commercial sector operating time of 12.3 hours per day, or more than 60 years in homes where average operation is 2.2 hours per day (DOE 2107). Some LED products report lifetimes as high as 100,000 hours. Common two-pin CFLs, on the other hand, report lifetimes of 10,000 to 12,000 hours, and four-pin CFLs have rated lifetimes of 10,000 to 24,000 hours. Typical CFL warranties run for 15 months.

Table 13 shows some examples of fluorescent and drop-in LED replacements for those lamps. The rated lifetimes of LED lamps are typically about three times longer than the fluorescent lamps they are replacing.

Table 13. Lifetime and warranty comparison for pin-based CFL and LED lamps

Pin-based CFLs			Pin-based LED replacements		
	Halco 32W 12in Diameter T9 4100K	10,000 hours, No warranty		Sylvania T9 Hybrid 16W (32W-Equiv.) / 3000–5000K G10q	36,000 hours, 10-year warranty
	Philips 13W G24q1 Warm White Double Twin Tube - 4-Pin	10,000 hours, 2-year warranty		Green Creative 6.5W Omni Directional G24q 3500K | Warm White - 4-Pin	50,000 hours, 5-year warranty
	Philips 40W 2G11 4100K Long Single Twin Tube - 4-pin	20,000 hours, 15-month warranty		Philips Non-Dimmable 16.5W 4000K 4-pin Single Twin Tube	50,000 hours, 5-year warranty

LED Replacements for Specialty Applications

In addition to the most common LFL products covered above (e.g., four-foot, eight-foot, and U-bend LFLs), we investigated the availability of LED replacements for less common lamp shapes and lengths as well as lamps designed for specialty applications. Many of these lamps are explicitly excluded or exempted from the DOE's minimum energy efficiency standards for fluorescent lighting. As LED technology has evolved and matured, LED replacements for these lamp types and applications have been introduced. These LED products are readily available and increasingly attractive mercury-free alternatives to fluorescent products.

Less Common Shapes and Lengths

Federal efficiency standards for general-service fluorescent lamps (i.e., LFLs) exclude alternate-length lamps (i.e., two-, three-, and five-foot lamps) as well as circline lamps. DOE has continued to exclude these lamp categories from standards because of their small market share—according to the latest lighting market characterization, these lamp categories together account for less than 1.5% of installed LFLs (DOE 2017a).

However, despite the small market share, these excluded fluorescent categories still account for more than 25 million installed lamps and a significant amount of mercury. LED replacements are available for each of these LFL lamp types, offering energy savings and longer lifetimes without the use of mercury. Table 14 summarizes key technical specifications for a sample of fluorescent and LED lamps in each of the excluded LFL categories.

Table 14. Fluorescent and TLED lamps in DOE's excluded categories

	Type	Product	Light output (lumens)	Wattage (W)	Lifetime (hours)
Circline	LFL	PLT Solutions 32W T5 Circline	2000	32	12,000
	LED	LEDvance SUBSTITUBE T9 EM	2000	20	30,000
2-foot T8	LFL	Philips 281899 – F17T8/TL841 ALTO	1375	17	24,000
	LED	TCP Dimmable 2' 4100K Glass	1200	9	50,000
3-foot T8	LFL	PLT Solutions Shatter Resistant	1950	25	20,000
	LED	Topaz LED Dual Mode Linear	1700	14	50,000
5-foot T8	LFL	Philips T8 Cool White	3725	40	24,000
	LED	ESL Vision 5-ft LED Plug and Play	2728	22	80,000
2D*	LFL	Philips PL-Q (GR10q) 4-pin	2050	28	13,000
	LED	Bonlux 2D retrofit LED, ballast bypass**	1800	18	35,000

*** 2D lamps are technically CFLs and are not included as covered or excluded products in the LFL standards. We include them here for completeness. ** Drop-in 2D replacements are readily available in the U.K. and EU markets.**

Specialty Lamps

Federal efficiency standards also provide exemptions for several lamps deemed to have specialty features or designed for use in specific applications. For some of the exempted categories, few, if any, fluorescent lamps are available. LED lamps are available for most categories as replacements for LFLs or for other light sources typically used in these applications. In most cases, available LED replacements outperform conventional light sources in these applications.

Plant growth lamps. Linear fluorescent lamps are employed in some commercial agricultural facilities, typically for limited use in seedling cultivation and early growth of grafted plants in non-stacked indoor farms and throughout the growth cycle in vertical farms. T5 and T5HO lamps are preferred in these applications. TLEDs provide the same light output using about 40% less power. More important, LEDs vastly outperform LFLs in photosynthetic photon efficacy (PPE), a measure of efficiency in the conversion of electrical energy to photons for use by plants. Fluorescents have a PPE of 0.84; LED systems achieve a PPE greater than 2.0, with further improvement expected (DOE 2017b).

Declining prices for LEDs have led many commercial producers to move away from LFLs in favor of LEDs, given their improved energy efficiency and photosynthetic photon efficacy. DOE (2020) estimates that TLEDs have replaced LFLs throughout the vertical farm sector but continue to account for only approximately 3% of lighting energy use in non-stacked indoor farms where high-intensity discharge (HID) lamps continue to hold the largest market share.

Cold temperature application lamps. Fluorescent lamp technology does not perform well in cold temperatures, and LFLs are not marketed for these applications (e.g., cold storage, food processing, exterior stairwells, parking garages, and outdoors). Fluorescent lamps with magnetic ballasts can usually operate in temperatures no lower than 50 °F. Some electronic ballasts work at 0 °F, and some rare models operate below 0 °F. LEDs are well suited for cold-temperature performance, with efficacy improving at lower temperatures. Standard LED lamps have operating temperatures down to –4 °F, and certain models are rated for operation at –20 °F or lower.

Colored fluorescent lights. LEDs are the better choice for colored lighting, as they can emit different colors from the same tube through the mix of diodes and different materials they contain. Fluorescent tubes, on the other hand, must be coated to emit a different-color light, and each tube can produce only one color.

Impact-resistant fluorescent lamps. LFLs with a coating designed to contain the glass if the lamp is broken, including those referred to as impact-resistant, shatter-resistant, shatterproof, or shatter-protected, are exempted from federal efficiency standards. Widely available plastic TLEDs offer an ideal alternative.

Reflectorized or aperture lamps. Reflectors or apertures are introduced into LFLs to help concentrate and direct light output from the diffuse fluorescent source. As directional light sources, LEDs are well suited for applications that previously used these specialty LFLs.

Reprographic equipment. LED replacement options for reprographic equipment (i.e., laser and ion printers, copiers, composing and typesetting equipment, platemaking and photographic equipment, and collating and binding equipment) appear limited. However, LEDs are gaining traction as a good alternative for subsections of this application. The low power consumption and long lifetimes of LEDs are beneficial for laser and inkjet printers, and they outperform fluorescent bulbs in platemaking equipment (FESPA 2014; TechRadar 2020; Esko 2019).

UV lamps. UV lamps are used in many specialized applications including lighted signs; avionics backlighting; the curing of inks, coatings, and adhesives; tanning; phototherapy; and purification and disinfection of air, water, and surfaces. LED alternatives have been introduced as replacements for most current uses of linear fluorescent UV lamps and are gaining share in many markets. These lamps are used in specialized applications and are not suited for general-service lighting. A full range of suitable LED replacements may not yet be available for some specialty UV applications (e.g., purification and disinfection), potentially justifying exemptions from policies designed to phase out fluorescent lamps.

High-CRI lamps (CRI ≥ 87). Enacted at a time when high-CRI lamps were rare, expensive, and used only for niche applications, this exemption became a loophole when it motivated manufacturers to bring to market low-cost, mass-market, high-CRI T12 and T8 lamps that are very inefficient. As a result, federal efficiency standards that took effect in 2012 that DOE expected would phase out T12s have been circumvented (ASAP 2018). Six states have enacted laws requiring these exempted lamps to meet the same efficiency standards as other LFLs (ASAP 2021). As illustrated in table 10 above, high-CRI linear LEDs are available to replace high-CRI fluorescent lamps.

Consumer Economic Impacts

Drop-in LED replacements for fluorescent lamps are very cost effective for purchasers. Tables 15–17 show the payback periods for common lamps used in the residential, commercial, and industrial sectors, respectively. For the most common lamp types used in households, four-foot T12 and T8 lamps, the estimated additional lamp costs of $2.28 and $1.18, respectively, pay back in lower utility bills within 1.2 and 1.0 years, respectively. Paybacks are even quicker in the commercial sector, where the largest number of fluorescent lamps are sold. The most common commercial lamp type, the four-foot T8, pays back its additional upfront cost within just two months. LEDs replacing 40-watt four-foot T12s in the commercial sector pay back in four months. Drop-in replacements are similarly cost effective for the less common lamp types and in the industrial sector.

Tables 15–17 also show estimated average life-cycle cost savings, which take into account both electricity savings and the additional upfront costs.[10] The average life-cycle cost savings are positive for all lamp types and sectors. Average life-cycle cost savings for ballast-bypass LED replacements are also positive for lamps in the commercial sector, including eight-foot high-output lamps.

Savings for Schools, Office Buildings, and Household Kitchens

A household may have a couple of fluorescent lamps in a kitchen or a few in a basement or garage. A school or municipal building may have hundreds, and an office building may have hundreds to thousands depending on its size. With the examples below, we show the total savings that may be gained by replacing the fluorescent lamps in some typical buildings with LEDs.

- For a typical school with 980 fluorescent lamps, replacing the existing lamps with drop-in LEDs would save the school about $3,700 per year on its electricity bills. Average life-cycle cost savings, taking into account the additional upfront cost of the LEDs, would be more than $24,000, and the payback period would be less than two months.
- For a typical small office building with 240 fluorescent lamps, replacing the existing lamps with drop-in LEDs would result in annual electricity bill savings of

[10] The life-cycle cost savings also take into account the residual value of the LED at the end of the fluorescent lamp's lifetime.

about $900. Average life-cycle cost savings would be more than $6,000, and the payback period would be less than two months.

- For a household kitchen with a two-lamp fluorescent fixture, replacing the lamps with drop-in LEDs would reduce the household's annual electricity bill by about $5. Average life-cycle cost savings would be about $50, and the payback period would be less than one year.

Note: These examples assume that all the existing fluorescent lamps in schools and office buildings are four-foot T8s, that the existing lamps in household kitchens are 40-watt four-foot T12s, and that all the lamps are replaced in 2023. The assumed daily operating hours for schools, office buildings, and household kitchens are 7.3 hours, 7.4 hours, and 2.8 hours, respectively. Savings calculations are based on national average electricity prices.

Table 15. Average life-cycle cost savings and payback periods for drop-in LED replacements in the residential sector

Baseline lamp type	Incremental cost (2020$)	First-year electricity bill savings (2020$)	Life-cycle cost savings (2020$)	Payback period (years)
4-foot T12 – 40 W	2.28	1.84	16	1.2
4-foot T8	1.18	1.22	11	1.0
Pin-based CFL	3.49	1.04	5	3.4

Table 16. Average life-cycle cost savings and payback periods for drop-in LED replacements in the commercial sector

Baseline lamp type	Incremental cost (2020$)	First-year electricity bill savings (2020$)	Life-cycle cost savings (2020$)	Payback period (years)
4-foot T12 – 40 W	2.59	8.52	44	0.3
4-foot T12 – 34 W	3.67	6.12	35	0.6
4-foot T8	0.54	4.14	27	0.1
4-foot T5	2.29	5.49	38	0.4
4-foot T5 high output	4.61	10.90	74	0.4
Pin-based CFL	3.02	6.81	22	0.4

Table 17. Average life-cycle cost savings and payback periods for drop-in LED replacements in the industrial sector

Baseline lamp type	Incremental cost (2020$)	First-year electricity bill savings (2020$)	Life-cycle cost savings (2020$)	Payback period (years)
4-foot T8	0.54	3.90	19	0.1
4-foot T5 high output	4.61	9.43	49	0.5
8-foot T12	13.82	12.65	32	1.1
8-foot T8	14.41	6.18	23	2.3

National and State-by-State Impacts

A full transition from fluorescent lamps to LEDs has the potential to provide large mercury reductions, CO_2 emissions reductions, and electricity bill savings for consumers and businesses. This section describes cumulative impacts through 2050 and the annual impacts in 2030 on a national and state-by-state basis. We also show the savings breakdown according to the baseline fluorescent lamps being replaced.

The total potential cumulative reduction of mercury in lamps shipped through 2050 is about 16,000 pounds (see table 18). Another 966 pounds of mercury would be avoided cumulatively through 2050 from coal-fired power plant emissions due to electricity savings. Total potential cumulative CO_2 emissions avoided through 2050 are 208 million metric tons (MMT). Total net present value savings, which take into account both savings and costs for households and businesses, are $44 billion, and the total benefit–cost ratio for the nation is 13.2, which means that the electricity bill savings outweigh the additional upfront costs by more than a factor of 13.

State-level savings scale with the size of a state's population and commercial building square footage. As a result, the four most populous states—California, Texas, Florida, and New York—have the largest savings potentials. The carbon intensity of a state's power supply affects CO_2 emissions reductions. For example, California, with a lower-carbon power supply mix than many states, has the second-largest mercury savings potential but the fourth-largest potential reduction in CO_2 emissions. States that have eliminated coal from their power supply have zero or close to zero mercury emissions reduction potential. California, which has comparatively high electricity prices, has the largest net present value savings of any state at $7 billion and one of the highest benefit–cost ratios, 23.4 to 1.

Table 18. Cumulative mercury avoided, emissions reductions, net present value savings, and benefit-cost ratio

State	Potential cumulative reductions through 2050			Net present value savings (million 2020$)	Total benefit–cost ratio
	Hg in lamps shipped (lbs)	Hg emissions (lbs)	CO_2 emissions (thous. MT)		
Alabama	252	12.8	3,670	600	10.6
Alaska	34	4.1	474	175	25.4
Arizona	260	5.5	1,516	546	10.6
Arkansas	150	3.8	2,305	342	10.4
California	1,503	1.0	11,385	7,002	23.4
Colorado	203	15.5	2,940	414	9.9
Connecticut	154	0.0	639	676	22.2
Delaware	45	6.0	449	127	14.2
District of Columbia	69	9.4	705	267	20.7
Florida	946	38.4	14,623	2,060	11.8
Georgia	499	20.2	6,673	1,103	11.0
Hawaii	46	1.2	1,024	348	33.7
Idaho	68	2.4	760	118	7.9
Illinois	673	42.5	8,064	1,588	11.3
Indiana	375	58.8	8,943	896	10.2
Iowa	167	19.3	2,851	360	8.9
Kansas	167	16.4	2,406	386	10.9
Kentucky	219	22.6	4,007	421	8.7
Louisiana	295	6.2	4,882	689	10.4
Maine	59	0.0	247	188	15.3
Maryland	279	35.1	2,878	806	15.5
Massachusetts	316	0.0	1,323	1,409	22.5
Michigan	515	56.2	10,917	1,348	12.6
Minnesota	262	27.1	4,123	600	10.6
Mississippi	148	7.5	2,437	349	10.9
Missouri	305	41.4	6,140	607	10.2
Montana	48	1.1	276	104	9.9

State	Potential cumulative reductions through 2050 Hg in lamps shipped (lbs)	Hg emissions (lbs)	CO_2 emissions (thous. MT)	Net present value savings (million 2020$)	Total benefit–cost ratio
Nebraska	108	13.5	1,915	230	9.5
Nevada	116	5.1	1,512	218	8.7
New Hampshire	57	0.0	239	235	20.0
New Jersey	511	68.7	5,135	1,927	19.5
New Mexico	87	3.1	752	179	9.5
New York	1,039	0.2	12,017	4,591	22.5
North Carolina	510	32.3	6,000	1,068	10.7
North Dakota	78	10.4	1,460	180	9.8
Ohio	650	58.0	10,673	1,424	10.2
Oklahoma	230	12.0	2,810	448	9.4
Oregon	223	0.1	694	444	9.8
Pennsylvania	675	83.9	8,210	1,597	10.7
Rhode Island	46	0.0	188	197	22.3
South Carolina	254	17.1	3,090	619	11.3
South Dakota	50	5.9	856	114	11.0
Tennessee	344	36.2	6,323	706	10.4
Texas	1,587	103.1	23,232	3,035	9.4
Utah	110	5.0	1,493	211	9.2
Vermont	28	0.0	117	109	18.4
Virginia	516	11.6	6,264	1,074	11.0
Washington	396	0.2	1,229	758	9.6
West Virginia	96	8.7	1,601	190	8.8
Wisconsin	328	33.4	5,146	786	11.2
Wyoming	44	2.6	702	96	8.2
United States	16,142	966	208,314	43,963	13.2

Figure 12 shows potential annual mercury reductions in lamps shipped and mercury and CO_2 emissions reductions. Annual mercury reductions in lamps shipped decline over time, as businesses and consumers switch to LEDs and shipments of fluorescents shrink accordingly.

The potential annual CO_2 and mercury emissions reductions from a policy measure to accelerate that transition are driven by the stock of affected lamps rather than by sales, and thus they peak later than the mercury reduction in lamps shipped since it takes time for the existing stock of fluorescent lamps to be replaced with LEDs.

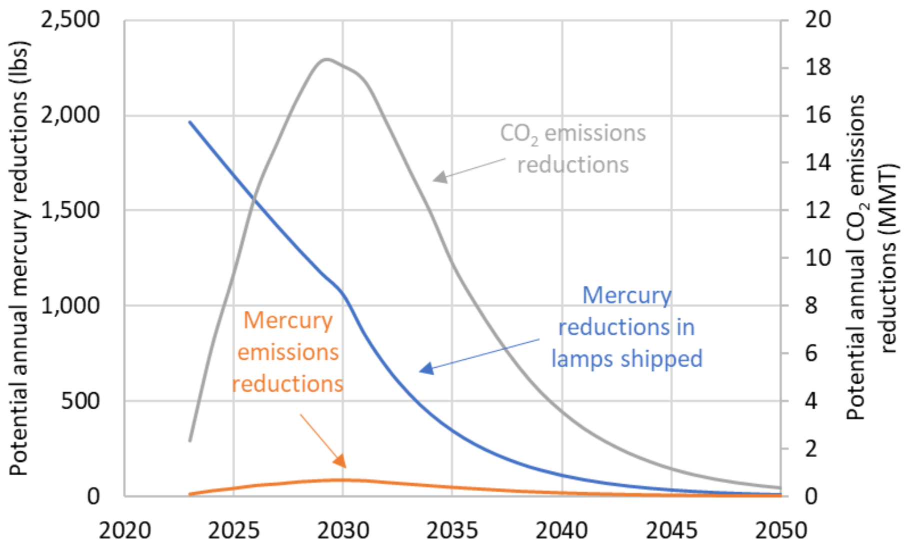


Figure 12. Potential annual mercury reductions in lamps shipped and mercury and CO_2 emissions reductions

Table 19 shows annual state-by-state and national potential annual mercury reductions in lamps shipped, mercury and CO_2 emissions reductions, and electricity and bill savings in 2030. Annual national electricity savings would reach more than 63 terawatt-hours, an amount equal to the total electricity used in the state of Minnesota (EIA 2021c). They would also cut annual CO_2 emissions by 18 million metric tons, an amount equal to the annual emissions of four million typical passenger cars. Nationwide, total potential annual mercury reductions in lamps shipped are about 1,060 pounds, and potential annual mercury emissions reductions are 85 pounds. Total potential electricity bill savings for households and businesses are $6.7 billion in 2030.

Table 19. Potential mercury, CO_2, electricity, and electricity bill savings in 2030

	Potential annual reductions in 2030				
State	Hg in lamps shipped (lbs)	Hg emissions (lbs)	CO_2 emissions (thous. MT)	Potential annual electricity savings in 2030 (GWh)	Potential annual electricity bill savings in 2030 (million 2020$)
Alabama	16.5	1.13	326	1,021	94
Alaska	2.2	0.37	41	131	26

State	Potential annual reductions in 2030			Potential annual electricity savings in 2030 (GWh)	Potential annual electricity bill savings in 2030 (million 2020$)
	Hg in lamps shipped (lbs)	Hg emissions (lbs)	CO_2 emissions (thous. MT)		
Arizona	17.1	0.84	147	966	83
Arkansas	9.8	0.32	203	600	54
California	98.7	0.09	958	5,628	1,042
Colorado	13.4	1.49	256	757	63
Connecticut	10.1	0.00	49	573	98
Delaware	3.0	0.50	37	173	20
District of Columbia	4.5	0.80	59	275	41
Florida	62.0	3.37	1,290	3,534	319
Georgia	32.7	1.77	592	1,942	172
Hawaii	3.1	0.10	88	175	50
Idaho	4.5	0.24	66	269	18
Illinois	44.1	3.56	677	2,670	246
Indiana	24.6	5.01	752	1,563	140
Iowa	11.0	1.67	246	702	56
Kansas	10.9	1.39	203	671	60
Kentucky	14.4	2.01	350	882	67
Louisiana	19.4	0.51	431	1,230	109
Maine	3.9	0.00	19	221	28
Maryland	18.3	2.93	238	1,045	124
Massachusetts	20.7	0.00	101	1,189	205
Michigan	33.8	5.02	944	2,017	206
Minnesota	17.2	2.30	350	1,034	92
Mississippi	9.7	0.66	214	594	55
Missouri	20.0	3.48	510	1,172	95
Montana	3.2	0.09	24	189	16
Nebraska	7.1	1.21	168	443	35
Nevada	7.7	0.52	132	452	33
New Hampshire	3.8	0.00	18	214	34

State	Potential annual reductions in 2030: Hg in lamps shipped (lbs)	Hg emissions (lbs)	CO_2 emissions (thous. MT)	Potential annual electricity savings in 2030 (GWh)	Potential annual electricity bill savings in 2030 (million 2020$)
New Jersey	33.5	5.76	425	1,987	293
New Mexico	5.8	0.35	69	342	28
New York	68.1	0.03	1,054	3,994	658
North Carolina	33.4	3.06	530	1,962	167
North Dakota	5.1	0.93	129	343	28
Ohio	42.7	5.12	920	2,609	223
Oklahoma	15.1	1.11	250	929	71
Oregon	14.6	0.004	61	880	68
Pennsylvania	44.3	7.15	690	2,720	250
Rhode Island	3.0	0.00	14	169	29
South Carolina	16.6	1.62	273	1,011	96
South Dakota	3.3	0.53	75	199	17
Tennessee	22.6	3.20	553	1,337	111
Texas	104.0	9.23	2,076	6,417	486
Utah	7.2	0.50	130	427	32
Vermont	1.8	0.00	9	105	16
Virginia	33.8	0.97	570	2,027	166
Washington	26.0	0.007	109	1,559	116
West Virginia	6.3	0.77	138	392	30
Wisconsin	21.5	2.82	436	1,311	121
Wyoming	2.9	0.26	62	200	15
United States	1,059	85	18,062	63,252	6,700

Figure 13 shows the breakdowns of total potential cumulative mercury reductions in lamps shipped through 2050 and cumulative CO_2 emissions reductions by baseline lamp type. Almost half of the mercury reductions and CO_2 emissions reductions come from four-foot T8 LFLs, with four-foot T12 LFLs providing the second-largest reductions. The contribution of four-foot T5 lamps to the potential CO_2 emissions reduction is significantly larger than their contribution to the mercury reductions due to the large per-unit energy savings for these lamps (in particular for T5 high-output lamps) and their relatively low mercury content per lamp.

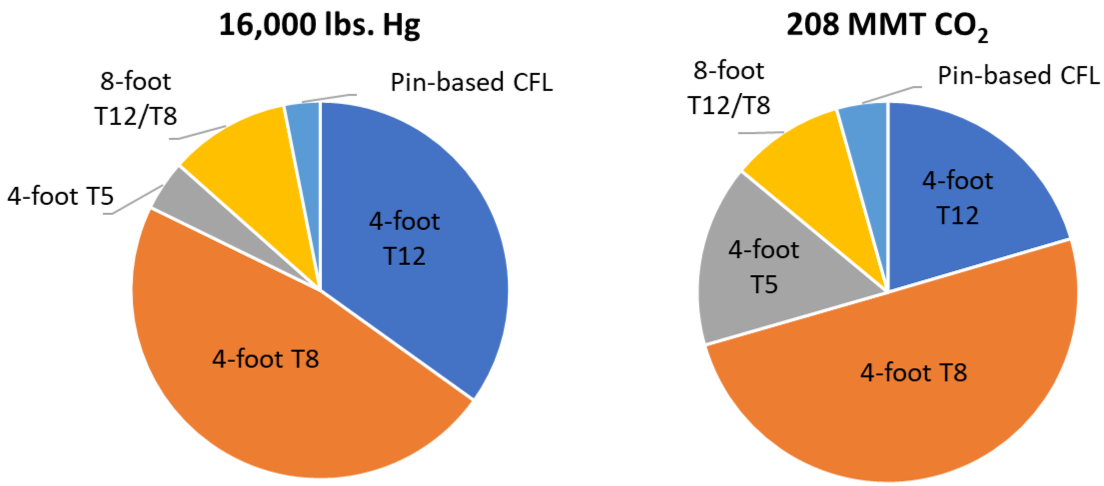


Figure 13. Breakdowns of total potential cumulative mercury reductions in lamps shipped through 2050 (left) and cumulative CO_2 emissions reductions (right) by baseline lamp type

Policy Overview

States and the federal government, as well as international bodies, have identified mercury as a toxic pollutant that poses a threat to human health and the environment and have enacted policies to control sources of this pollution. These extensive existing policies demonstrate the well-established public policy interest in eliminating sources of mercury pollution when feasible. The following section discusses current policies at each governmental level that regulate mercury-added products.

STATE POLICY

Since 1999, 24 states have adopted legislation regulating mercury-added products separate from federal universal hazardous waste regulations.[11] A common reason for these regulations cited in legislative findings is that mercury is a persistent and toxic pollutant that bioaccumulates in the environment when released from the improper disposal of mercury-containing products or from coal-fired power plants and poses a threat to human health through consumption of mercury-contaminated seafood.

[11] The 24 states are California, Connecticut, Florida, Illinois, Indiana, Iowa, Louisiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Montana, Nebraska, New Hampshire, New Jersey, New York, Ohio, Oregon, Pennsylvania, Rhode Island, Washington, Wisconsin, and Vermont.

Specific mercury regulations differ by state, but most fall into one of these common categories:

- Prohibitions on the sale of certain mercury-added products. Of the 23 states with this policy, only four include lamps. None prohibit the sale of common fluorescent lamps.
- Collection, disposal, and/or recycling requirements. Of the 23 states with these requirements in place, 11 include lamps.
- Requiring that information be made available to consumers and/or the state regarding the mercury content of products. Thirteen states have enacted this policy, including 10 that extend the coverage to lamps.
- State building and/or school alternative purchasing requirements. None of the five states with these requirements include lamps.

Table 20 shows the categories of mercury policy adopted in each state. While states have commonly found that removal of mercury-containing products from the waste stream is an effective way to reduce mercury pollution, few states restrict sales of fluorescent lamps. Instead, states have mostly chosen to regulate the end-of-life disposal of these lamps. California and Vermont have adopted restrictions on the use of certain dangerous materials similar to the European Union’s (EU) Restriction of the Use of Hazardous Substances (RoHS), its mercury control policy. While the EU recently adopted revisions to its RoHS policy that will effectively phase out common fluorescent lamps as of 2023, state policies in California and Vermont have not been updated to eliminate exemptions for fluorescent lamps.

Appendix D provides additional data on states that have enacted mercury control policies as well as example language from these regulations.

Table 20. State mercury regulations beyond federal universal hazardous waste restrictions

	Collection, disposal, and/or recycling requirements	Ban on sale of certain mercury products	Information disclosure requirements	Alternative purchasing rules for schools and/or state buildings
California	*	*	*	
Connecticut	**	*	**	
Florida	*	*	*	
Illinois	*	*		
Indiana	*	*		
Iowa	*	*		
Louisiana	**	**	**	
Maine	**	*	**	*
Maryland	**	*		
Massachusetts	**	*	**	*

	Collection, disposal, and/or recycling requirements	Ban on sale of certain mercury products	Information disclosure requirements	Alternative purchasing rules for schools and/or state buildings
Michigan	*	*		*
Minnesota	**	**	**	
Montana	*	*		
Nebraska	*	*		
New Hampshire	**	*	**	
New Jersey				
New York	**	*	**	*
Ohio	*	*		
Oregon	*	**	*	
Pennsylvania	*	*		
Rhode Island	**	**	**	*
Washington	**	*	**	
Wisconsin	*	*		
Vermont	**	*	**	

*** Indicates policy covers mercury products, but does not cover lamps**
**** Indicates policy covers mercury products, including lamps**

FEDERAL POLICY

The federal government has enacted multiple policies regulating sources of mercury pollution. However, as with state policies, federal regulation of fluorescent lamps focuses primarily on end-of-life product disposal. Federal policies do not prohibit the sale of fluorescent lamps. Regulations covering mercury pollution include:

Universal hazardous waste restrictions. Require disposal management for certain hazardous materials, including mercury-added lamps, to prevent dangerous pollution releases into the environment. The regulations, administered by the U.S. Environmental Protection Agency (EPA), do not prevent the sale of mercury-added lamps and only govern end-of-life disposal.

Mercury Export Ban Act of 2008. Prohibits federal agencies from conveying, selling, or distributing mercury under their jurisdiction. Also prohibits the export of elemental mercury from the United States.

Clean Air Act. Requires certain air pollution sources that emit mercury to obtain an operating permit and meet technology-based standards for mercury emissions.

Clean Water Act. Prohibits release of mercury into waters without a permit from the EPA or a state authorized by EPA.

Mercury-Containing and Rechargeable Battery Management Act of 1996. Phased out mercury in batteries and created battery disposal programs.

Emergency Planning and Community Right-to-Know Act. Requires reporting of emissions of chemicals, including mercury, from federal and industrial facilities.

Resource Conservation and Recovery Act. Requires EPA to manage the generation, storage, transportation, treatment, and disposal of mercury waste, which must meet the agency's treatment and recycling standards before being disposed of. Household hazardous waste and waste types generated in very small quantities are exempt.

Safe Drinking Water Act. Grants EPA authority to set standards limiting the level of mercury in public water systems.

INTERNATIONAL POLICY

International bodies and governments outside the United States have adopted policies regulating light sources and mercury pollution and have signed agreements with the goal of reducing mercury pollution. These include:

Europe—Ecodesign Directive. Passed by the EU in 2005, the Ecodesign Directive sets minimum energy efficiency and quality requirements for a range of products sold in the EU, including lighting products. Although it does not directly regulate mercury, by setting technology-neutral efficiency requirements at levels that fluorescents cannot meet, the directive has the effect of phasing out some mercury lamps. In September 2021, new Ecodesign requirements came into force that effectively eliminated integrally ballasted CFLs and T2 and T12 LFLs from the EU market. A second tier of Ecodesign will take effect in September 2023, phasing out the most popular T8 LFLs (two-, four-, and eight-foot lamps).

Europe—Restriction of the Use of Certain Hazardous Substances (RoHS) Directive. Passed by the EU in 2003, RoHS limits or bans 10 substances including mercury, lead, cadmium, hexavalent chromium, and others. In relation to mercury content in lighting, RoHS sets a maximum amount of mercury in fluorescent lamps, with the current limits having been set in 2011 (Directive 2011/65/EU). In December 2021, the EU published final policy updates for all the mercury-containing lighting products covered by RoHS to remove all exemptions for general-purpose CFLs and LFLs. Thus, all fluorescent lamps will be phased out of the EU market in 2023.

International—Minamata Convention on Mercury. Minamata is an international pact that entered into force in August 2017 following ratification by 50 countries; as of December 2021, there were 136 parties to the convention. Major highlights include a ban on new mercury mines and the phaseout of existing ones, the phaseout or phasedown of mercury use in a number of products and processes, and control measures on emissions to air and on releases to land and water. Yet despite this progress, the Minamata Convention contains exemptions for mercury-containing fluorescent lamps, citing insufficient cost-effective mercury-free alternatives. While those exemptions were justified in 2013 when the convention was drafted, the innovation and development of mercury-free LED retrofit lamps means the fluorescent exemptions under Minamata are no longer needed, nor are they justified.

In 2021 the African States proposed an amendment to the Minamata Convention that would effectively ban fluorescent lamps. This proposal will be discussed at the Fourth Conference of the Parties, an in-person meeting planned for March 2022. If adopted, this provision would represent a critical step toward a global phaseout of fluorescent lamps. In the United States, state action to phase out fluorescent lamps would be an important precursor to federal action under the Minamata Convention.

These policy actions are part of a growing movement by countries around the world to eliminate mercury in lighting products. Other actions include the following:

- The **United Kingdom**'s Energy-Related Products Policy Framework proposes new, two-tier lighting efficacy standards exceeding current EU Ecodesign levels: 120 lumens per watt in 2023 and 140 lumens per watt in 2025. These efficacy levels cannot be met with fluorescent technology.
- The **Southern African Development Community** (SADC), a coalition of 16 countries, has adopted efficiency standards that phase out all LFLs and CFLs by 2024 and require certain high-volume new indoor and outdoor luminaires to use LEDs.
- The six-nation **East African Community** (EAC) is on track to finalize new standards in the first quarter of 2022 aligning with the SADC standards for lamps and luminaires.
- In **India**, the national lighting industry association (ELCOMA) is pursuing a road map seeking to make India the world's second-largest manufacturer and exporter of LED lighting and to fully convert the country's lighting market to LEDs by 2024.
- In 2019, **Canada** published a national strategy for phasing out fluorescent lighting over the 2023–2028 time frame. An updated draft with earlier deadlines is expected to be released in early 2022.
- The United Nations Environment Programme's **United for Efficiency** (U4E) initiative published model regulations in 2021 to support government efforts to eliminate fluorescent lighting. The model regulations would phase out CFL and LFL technologies between 2023 and 2025.

Conclusion

Mercury is a persistent and toxic pollutant that poses a threat to human health and the environment. In this country, states and the federal government have adopted regulations to ban sales of many mercury-containing products and to control their disposal. The advent of mercury-free, energy-efficient LED lighting presents the opportunity to transition away from mercury-containing fluorescent lighting and achieve large reductions in mercury pollution and CO_2 emissions as well as electricity bill savings for consumers and businesses. A nationwide phaseout of fluorescent lamps would avoid 16,000 pounds of mercury in lamps shipped and 208 million metric tons of CO_2 emissions by 2050. The phaseout would save consumers and businesses $44 billion on a net present value basis. A phaseout could be accomplished either with regulations restricting mercury in lamps or through new federal lamp efficiency standards.

LED replacements for fluorescent lamps are widely available and cost effective for consumers and businesses. While adoption of LED technologies is growing, absent policy action, a full transition from fluorescents to LEDs will take many years. Following the example set by the European Union and other governments, state and federal policymakers in the United States should phase out most fluorescent lamps. This would reduce the harmful impact of mercury on people and the environment and achieve large climate and economic benefits.

References

ASAP (Appliance Standards Awareness Project). 2018. "Lighting standards loophole jeopardizes energy and cost savings for fluorescent tubes." March 23. appliance-standards.org/blog/lighting-standards-loophole-jeopardizes-energy-and-cost-savings-fluorescent-tubes.

_____. 2021. "State Standards." appliance-standards.org/states - states-table.

Bennich, P., and M. Scholand. 2019. *Evidence of the Availability of Mercury-Free Alternative Products to Certain Fluorescent Lamps: Report to the Committee on the Restriction of Hazardous Substances*. Stockholm: SEA (Swedish Energy Agency). Washington, DC: CLASP (Collaborative Labeling and Appliance Standards Program). www.clasp.ngo/research/all/mercury-free-alternatives-to-certain-fluorescent-lamps-a-report-to-the-european-commissions-committee-on-the-regulation-of-hazardous-substances/.

_____. 2020. *Assessing Annex III Fluorescent Lamp Exemptions in the Light of Scientific and Technical Progress: Report to the Committee on the Restriction of Hazardous Substances.* Stockholm: SEA. Washington, DC: CLASP. www.clasp.ngo/research/all/assessing-annex-iii-fluorescent-lamp-exemptions-in-the-light-of-scientific-and-technical-progress/.

DOE (U.S. Department of Energy). 2014. *National Impacts Analysis and Shipments Analysis for DOE's Final Rule Analysis for GSFL and IRL.* December. www.regulations.gov/document?D=EERE-2011-BT-STD-0006-0062.

_____. 2016. *Notice of Proposed Rulemaking Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: General Service Lamps.* February. www.regulations.gov/document/EERE-2013-BT-STD-0051-0042.

_____. 2017a. *2015 U.S. Lighting Market Characterization*. Washington, DC: DOE. www.energy.gov/eere/ssl/2015-us-lighting-market-characterization.

_____. 2017b. *Energy Savings Potential of SSL in Horticultural Applications.* Washington, DC: DOE. www.energy.gov/sites/prod/files/2017/12/f46/ssl_horticulture_dec2017.pdf.

_____. 2019. *Energy Savings Forecast of Solid-State Lighting in General Illumination Applications.* Washington, DC: DOE. www.energy.gov/sites/default/files/2020/02/f72/2019_ssl-energy-savings-forecast.pdf.

_____. 2020a. *2019 Lighting R&D Opportunities*. Washington, DC: DOE. www.energy.gov/sites/prod/files/2020/01/f70/ssl-rd-opportunities2-jan2020.pdf.

_____. 2020b. *Adoption of Light-Emitting Diodes in Common Lighting Applications.* Washington, DC: DOE. www.energy.gov/sites/default/files/2020/09/f78/ssl-led-adoption-aug2020.pdf.

_____. 2020c. *Notice of Final Determination Technical Support Document Energy Conservation Program for Consumer Products and Certain Commercial and Industrial Equipment: Fluorescent Lamp Ballasts.* December. www.regulations.gov/document/EERE-2015-BT-STD-0006-0032.

EIA (Energy Information Administration). 2015. *2012 Commercial Buildings Energy Consumption Survey.* www.eia.gov/consumption/commercial/data/2012/index.php?view=consumption.

_____. 2020. *Annual Energy Outlook 2020.* January. www.eia.gov/aeo.

_____. 2021a. *2018 Manufacturing Energy Consumption Survey*. February. www.eia.gov/consumption/manufacturing/data/2018/#r5.

_____. 2021b. *Electricity Sales to Ultimate Customers by State by Sector by Provider (EIA-861).* www.eia.gov/electricity/data/state/.

_____. 2021c. "State Electricity Profiles." www.eia.gov/electricity/state/.

Esko. 2019. *Flexo Platemaking: Comparative Analysis Confirms UV LED Outperforms Conventional Exposure*. Ghent: Esko. cdn.ymaws.com/www.aiccbox.org/resource/resmgr/Esko_XPS_Whitepaper_079_us.pdf.

FESPA. 2014. "Why LED Curing is Important for Your Print Shop." www.fespa.com/en/news-media/features/why-led-curing-is-important-for-your-print-shop.

Granda, C. 2018. "Lighting Standards Loophole Jeopardizes Energy and Cost Savings for Fluorescent Tubes." *ASAP Blog*, March 23. www.appliance-standards.org/blog/lighting-standards-loophole-jeopardizes-energy-and-cost-savings-fluorescent-tubes.

Maxson, P., M. Bender, and A. Culver. 2021. *Mercury in Fluorescent Lighting: Unnecessary Health Risks and Actionable Solutions*. Washington, DC: Clean Lighting Coalition. cleanlightingcoalition.org/resources/mercury-in-fluorescent-lighting-report/.

NEMA (National Electrical Manufacturers Association). 2021a. "A-Line Lamp Shipments Continue to Decline in the Third Quarter 2021." www.nema.org/analytics/indices/view/led-a-line-lamp-shipments-decrease-in-fourth-quarter-2019-compared-to-third-quarter-2019-and-the-previous-year.

_____. 2021b. "Linear Fluorescent Lamp Shipments Indexes Show Mixed Results in Third Quarter 2021 Compared to Previous Year." www.nema.org/analytics/indices/view/linear-fluorescent-lamp-indexes-post-mixed-results-in-fourth-quarter.

Scholand, M., and P. Bennich. 2021. "Mercury and RoHS: The Link between Environmental Regulations and Efficiency." *ECEEE 2021 Summer Study on Energy Efficiency: A New Reality?* Stockholm: ECEEE (European Council for an Energy Efficient Economy).

www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2021/9-products-appliances-ict/mercury-and-rohs-the-link-between-environmental-regulations-and-efficiency/.

Signify. 2021a. "Philips LED lamps: InstantFit lamps bulletin." May. www.assets.signify.com/is/content/Signify/Assets/philips-lighting/united-states/20210706-instantfit-bulletin.pdf.

Signify 2021b. "Philips Lighting: High performance LED replacements for conventional T5 lamps." www.usa.lighting.philips.com/api/assets/v1/file/PhilipsLighting/content/comf7403345-pss-en_us/LP_CF_7403345_EU.en_US.PROF.CF.pdf.

TechRadar. 2020. "Inkjet vs Laser vs LED: what's best for you?" September 6. www.techradar.com/news/inkjet-vs-laser-vs-led-whats-best-for-you.

TRC. 2019. "Memo Re: Statewide interior lighting standard practices study: final analysis." October 15. https://trccompanies.sharepoint.com/sites/AE-Projects/SCELEDStd/Shared Documents/Task 4 Draft and Final Report/TRC SCE Interior Lighting_Final Analysis Memo_10-8-2019.docx.

Appendix A. Potential Cumulative Electricity Bill Savings

Table A1. State-by-state potential cumulative electricity bill savings through 2050

State	Potential cumulative electricity bill savings through 2050 (million 2020$)
Alabama	1,088
Alaska	302
Arizona	1,006
Arkansas	626
California	12,219
Colorado	765
Connecticut	1,181
Delaware	228
District of Columbia	466
Florida	3,733
Georgia	2,000
Hawaii	594
Idaho	225
Illinois	2,883
Indiana	1,625
Iowa	667
Kansas	697
Kentucky	784
Louisiana	1,259
Maine	336
Maryland	1,440
Massachusetts	2,458
Michigan	2,424
Minnesota	1,092
Mississippi	636

State	Potential cumulative electricity bill savings through 2050 (million 2020$)
Missouri	1,110
Montana	191
Nebraska	425
Nevada	411
New Hampshire	412
New Jersey	3,383
New Mexico	333
New York	8,027
North Carolina	1,949
North Dakota	329
Ohio	2,604
Oklahoma	831
Oregon	821
Pennsylvania	2,921
Rhode Island	345
South Carolina	1,120
South Dakota	208
Tennessee	1,293
Texas	5,643
Utah	395
Vermont	191
Virginia	1,965
Washington	1,407
West Virginia	354
Wisconsin	1,421
Wyoming	180
United States	**79,001**

Appendix B. Potential Annual Savings in 2035

Table B1. State-by-state potential annual mercury reductions in lamps shipped and mercury and CO_2 emissions reductions in 2035

State	Potential annual reductions in 2035			Potential annual electricity savings in 2035 (GWh)	Potential annual electricity bill savings in 2035 (million 2020$)
	Hg in lamps shipped (lbs)	Hg emissions (lbs)	CO_2 emissions (thous. MT)		
Alabama	5.4	0.58	173	587	54
Alaska	0.7	0.20	23	78	16
Arizona	5.6	0.01	63	582	52
Arkansas	3.2	0.17	107	348	32
California	32.3	0.00	488	3,409	641
Colorado	4.4	0.69	134	451	39
Connecticut	3.3	0.00	30	348	62
Delaware	1.0	0.33	21	104	12
District of Columbia	1.5	0.52	34	165	25
Florida	20.3	1.81	684	2,155	191
Georgia	10.7	0.96	321	1,153	100
Hawaii	1.0	0.06	49	104	30
Idaho	1.5	0.11	35	155	11
Illinois	14.4	2.11	406	1,566	146
Indiana	8.0	2.85	444	884	79
Iowa	3.6	0.92	137	392	33
Kansas	3.6	0.81	119	392	35
Kentucky	4.7	0.99	198	508	39
Louisiana	6.3	0.27	224	704	64
Maine	1.3	0.00	11	132	17
Maryland	6.0	1.93	141	638	77
Massachusetts	6.8	0.00	61	720	128
Michigan	11.1	2.67	525	1,190	122
Minnesota	5.6	1.33	204	602	54
Mississippi	3.2	0.33	116	345	32

State	Potential annual reductions in 2035: Hg in lamps shipped (lbs)	Hg emissions (lbs)	CO_2 emissions (thous. MT)	Potential annual electricity savings in 2035 (GWh)	Potential annual electricity bill savings in 2035 (million 2020$)
Missouri	6.5	2.10	315	700	55
Montana	1.0	0.05	13	110	10
Nebraska	2.3	0.65	94	254	22
Nevada	2.5	0.23	71	264	21
New Hampshire	1.2	0.00	11	129	21
New Jersey	11.0	3.79	246	1,197	179
New Mexico	1.9	0.10	33	200	17
New York	22.3	0.00	351	2,409	424
North Carolina	10.9	1.45	300	1,173	98
North Dakota	1.7	0.51	71	192	16
Ohio	14.0	2.77	548	1,518	131
Oklahoma	4.9	0.60	136	542	42
Oregon	4.8	0.002	33	519	42
Pennsylvania	14.5	4.37	394	1,573	150
Rhode Island	1.0	0.00	9	103	18
South Carolina	5.4	0.75	152	589	56
South Dakota	1.1	0.29	42	117	11
Tennessee	7.4	1.59	319	795	66
Texas	34.0	4.92	1,091	3,752	290
Utah	2.4	0.23	71	251	20
Vermont	0.6	0.00	5	62	10
Virginia	11.1	0.54	276	1,212	101
Washington	8.5	0.004	58	920	72
West Virginia	2.1	0.41	81	224	18
Wisconsin	7.0	1.64	255	765	71
Wyoming	0.9	0.11	31	108	9
United States	347	47	9,757	37,389	4,059

Appendix C. Methodology and Assumptions for Savings Analysis

We estimated savings for the specific categories of baseline LFLs and CFLs. These estimates are shown in table C1.

Table C1. Baseline lamp categories analyzed

Linear fluorescent lamps	Compact fluorescent lamps
4-foot T12 – 40 W	Pin-based
4-foot T12 – 34 W	
4-foot T8	
4-foot T5	
4-foot T5 high output	
8-foot T12	
8-foot T12 high output	
8-foot T8	
8-foot T8 high output	

ANNUAL SHIPMENTS

We estimated annual shipments of LFLs by starting with data on historical and projected shipments of LFLs and tubular LED (TLED) replacements for LFLs from the 2015 U.S. Department of Energy (DOE) final rule for energy conservation standards for general-service fluorescent lamps (GSFLs) (DOE 2014). We then used data from the National Electrical Manufacturers Association (NEMA) on the market penetration of TLEDs from 2015–2020 to adjust DOE's estimates of LFL shipments for 2015–2020 to account for the higher TLED market penetration as reported by NEMA relative to DOE's projections (NEMA 2021b). (NEMA reported that TLED market penetration reached about 32% in 2020; DOE's projection was roughly 10%.)

To calculate total shipments by major lamp category (e.g., four-foot T12, four-foot T8), we first estimated total shipments of eight-foot T12 and eight-foot T8 lamps for 2015–2020 based on the adjusted DOE estimates of total LFL shipments and DOE's estimates of eight-foot T12 and eight-foot T8 lamps as a portion of total LFL shipments. We then calculated total four-foot T12 and four-foot T8 lamps by first calculating total T12 and T8 shipments based on the adjusted DOE estimates of total LFL shipments and the market penetration of T12 and T8 lamps from the NEMA data. We then subtracted the estimated shipments of eight-foot T12 and eight-foot T8 lamps, respectively, from the estimates of total T12 and T8 shipments to calculate shipments of four-foot T12 and four-foot T8 lamps. Finally, we calculated total four-foot T5 shipments based on the adjusted DOE estimates of total LFL shipments and the market penetration of T5 lamps from the NEMA data.

We then used these estimates of total shipments by major lamp category for 2015–2020 to calculate average annual rates of change in shipments for that period. Table C2 shows the estimated average annual rate of change in shipments for each lamp category.

Table C2. Average annual change in shipments for 2015–2020 by linear lamp category

Lamp category	Average annual rate of change in shipments for 2015–2020
4-foot T12	–3%
4-foot T8	–6%
4-foot T5	–8%
8-foot T12	–25%
8-foot T8	–2%

We assumed that the annual rates of decline in shipments shown in table C2 would double by 2030 for all lamp categories except for eight-foot T12s. Since we assumed an initial high rate of decline for eight-foot T12 lamps (25%), we used this rate of decline throughout the analysis period. For the remaining lamp categories, we assumed that after 2030, the annual rate of decline would increase to 20% and remain constant through 2050.

For pin-based CFLs, we estimated 2015 shipments based on the 2015 stock in the residential and commercial sectors (DOE 2017a) and average lamp lifetimes (DOE 2016).[12] We used the same rates of decline in shipments of pin-based CFLs as those for four-foot T8 lamps.

Figure C1 shows the assumed total annual shipments of LFLs and CFLs through 2050.

[12] We assumed that the average lifetimes of pin-based CFLs are equivalent to those of Type A (i.e., medium screw-base) CFLs.

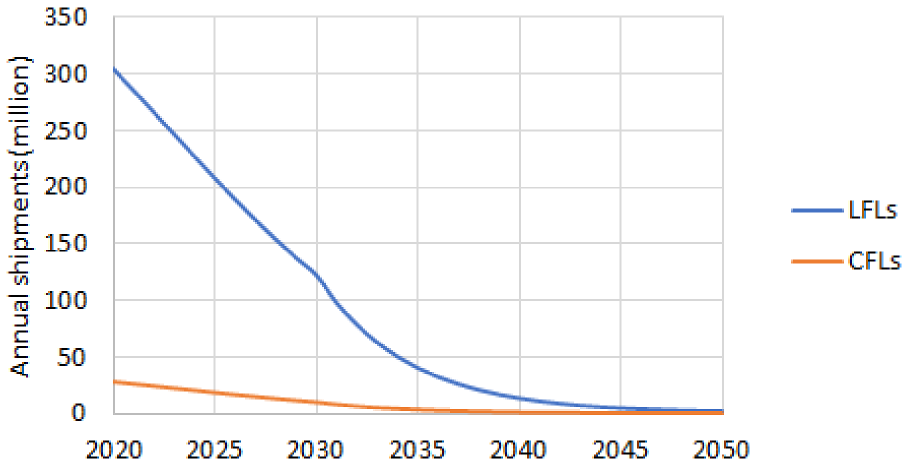


Figure C1. Assumed annual shipments of LFLs and CFLs

We allocated the total shipments of each LFL category (e.g., four-foot T8) to the residential, commercial, and industrial sectors by starting with data on the 2015 stock from the 2015 LMC and estimates of average lifetimes. We calculated average lifetimes based on the average annual operating hours from the 2015 LMC and the assumed rated lamp lifetimes shown in table C3 from the 2015 DOE final rule for GSFLs. (For the eight-foot lamps, we used a weighted average of the rated lifetimes for eight-foot standard-output and eight-foot high-output lamps.)

Table C3. Assumed average annual operating hours and rated lifetimes for LFLs

Lamp type	Sector	Average annual operation (hrs)	Rated lifetime (hrs)
4-foot T12 – 40 W	Residential	694	15,000
	Commercial	3,066	20,000
4-foot T12 – 34 W	Commercial	3,066	24,000
4-foot T8	Residential	767	24,000
	Commercial	2,920	24,000
	Industrial	4,380	24,000
4-foot T5	Residential	949	30,000
	Commercial	3,176	30,000
	Industrial	4,380	30,000
8-foot T12	Residential	584	12,000

Lamp type	Sector	Average annual operation (hrs)	Rated lifetime (hrs)
	Commercial	3,322	12,000
	Industrial	4,380	12,000
8-foot T8	Residential	548	24,000
	Commercial	3,066	24,000
	Industrial	4,380	24,000
8-foot T8 high output	Commercial	3,066	18,000
	Industrial	4,380	18,000

We then estimated 2015 annual shipments by dividing the 2015 stock by the average lifetime for each lamp category and sector. Table C4 shows the resulting estimated breakdown of annual shipments within each lamp category.

Table C4. Estimated breakdown of shipments of each linear lamp category by sector

Lamp type	Sector	% of estimated annual shipments within lamp category
4-foot T12	Residential	28%
	Commercial	72%
4-foot T8	Residential	8%
	Commercial	82%
	Industrial	9%
4-foot T5	Residential	8%
	Commercial	63%
	Industrial	29%
8-foot T12	Residential	12%
	Commercial	57%
	Industrial	31%
8-foot T8	Residential	8%
	Commercial	45%
	Industrial	47%

Finally, we applied the estimated breakdown of shipments along with the following assumptions to further break down estimated annual shipments by sector:

- Four-foot T12: We assumed that all residential T12 lamps are 40-W lamps. To break down commercial shipments between 40-W and 34-W lamps, we used data from NEMA on the portion of T12 lamps sold through the retail and commercial channels and the breakdown of 40-W versus 34-W lamps sold through the commercial channel. (We assumed all T12 lamps sold through the retail channel are 40-W lamps.)
- Four-foot T8: We allocated the T8 lamps to the residential, commercial, and industrial sectors based on the estimated breakdown of annual shipments in table C4.
- Four-foot T5: We assumed that all T5 lamps in the residential sector are standard-output lamps, and that all T5 lamps in the industrial sector are high-output lamps. We then allocated the remaining T5 standard-output and high-output lamps to the commercial sector.
- Eight-foot T12: We assumed that all eight-foot T12 lamps in the residential sector are standard-output lamps and that the ratio of standard-output to high-output lamps is the same in the commercial and industrial sectors.

- Eight-foot T8: We assumed that all eight-foot T8 lamps in the residential sector are standard-output lamps and that the ratio of standard-output to high-output lamps is the same in the commercial and industrial sectors.

INPUT WATTAGES AND PER-UNIT SAVINGS

For LFLs, we used information on baseline lamps from DOE's analyses for the 2009 and 2015 final rules for GSFLs.[13] Table C5 shows the assumed nominal wattage, rated wattage, ballast factor, and ballast efficiency for each baseline lamp and sector.

Table C5. Assumed wattage, ballast factor, and ballast efficiency for each baseline linear lamp type and sector

Baseline lamp type	Sector	Nominal wattage (W)	Input wattage (W)	Ballast factor	Ballast efficiency
4-foot T12 – 40 W	Residential	40	35.0	0.68	80%
	Commercial	40	43.0	0.95	91%
4-foot T12 – 34 W	Commercial	34	36.0	0.88	83%
4-foot T8	Residential	32	28.3	0.87	89%
	Commercial/industrial	32	27.7	0.88	92%
4-foot T5	Residential/commercial	28	30.2	1.00	92%
4-foot T5 high output	Commercial/industrial	54	58.3	1.00	92%
8-foot T12	Residential/commercial/ industrial	75	79.0	0.94	89%
8-foot T12 high output	Commercial/industrial	110	118.5	0.95	91%
8-foot T8	Residential/commercial/ industrial	59	53.3	0.87	93%
8-foot T8 high output	Commercial/industrial	86	89.7	0.95	89%

Except for eight-foot high-output lamps, for T12s we evaluated only Type A LED replacements since we found 100% ballast compatibility for drop-in replacements. (For

[13] See Tables 5.3.6 and 5.3.8 in the 2009 Fluorescent and Incandescent Lamps Final Rule Technical Support Document and Tables 5.3.8, 5.3.12, 5.3.21, 5.3.26, 5.3.31, and 5.3.36 in the 2014 General Service Fluorescent Lamps and Incandescent Reflector Lamps Final Rule Technical Support Document.

eight-foot T12 high-output lamps, we evaluated only Type B LED replacements due to limited availability of Type A lamps.) For T8s and T5s, we evaluated both Type A and Type B LED replacement lamps. Since Type B LED lamps bypass the existing ballast, the input wattage for these lamps is equivalent to the nominal wattage. For Type A LED lamps, which operate with the existing fluorescent ballast, we calculated input wattage using the ballast factors and ballast efficiencies in table C5 as:

$$Input\ wattage = \frac{Nominal\ wattage\ \times Ballast\ factor}{Ballast\ efficiency}$$

Table C6 shows the nominal wattages we assumed for linear LED replacement lamps based on products available in the market and the calculated input wattages for Type A LED lamps.

Table C6. Assumed wattages for Type A and Type B linear LED lamps

		Type A LED		
Baseline lamp type	Sector	Nominal wattage (W)	Input wattage (W)	Type B LED nominal/input wattage (W)
4-foot T12 – 40 W	Residential	17	15	--
	Commercial	17	18	--
4-foot T12 – 34 W	Commercial	17	18	--
4-foot T8	Residential	16	16	16
	Commercial/industrial	15	15	15
4-foot T5	Residential	14	15	14
	Commercial	13	14	14
4-foot T5 high output	Commercial/industrial	25	27	25
8-foot T12	Residential	41	43	--
	Commercial/industrial	35	37	--
8-foot T12 high output	Commercial/industrial	--	--	43
8-foot T8	Residential	41	38	43
	Commercial/industrial	35	33	43
8-foot T8 high output	Commercial/industrial	--	--	43

We then calculated per-unit annual energy use for the baseline lamp and the LED replacement for each of the lamp types and sectors using the assumed input wattages shown in table C6 and the annual operating hours shown in table C3. Table C7 shows the per-unit annual energy use for the baseline lamps and the LED replacements and the resulting per-unit energy savings for each lamp type and sector.

Table C7. Per-unit annual energy savings for linear lamps

Baseline lamp type	Sector	Baseline per-unit annual energy use (kWh)	LED per-unit annual energy use (kWh)		Per-unit annual energy savings (kWh)	
			Type A	Type B	Type A	Type B
4-foot T12 – 40 W	Residential	24.3	10.1	--	14.2	--
	Commercial	131.8	53.9	--	78.0	--
4-foot T12– 34 W	Commercial	110.4	54.4	--	56.0	--
4-foot T8	Residential	21.7	12.3	12.0	9.4	9.6
	Commercial	80.7	42.8	45.0	37.9	35.8
	Industrial	121.1	64.2	67.5	56.9	53.7
4-foot T5	Residential	28.7	14.0	12.8	14.6	15.8
	Commercial	95.9	45.7	42.9	50.2	53.0
4-foot T5 high output	Commercial	185.0	85.2	79.4	99.7	105.6
	Industrial	255.1	117.6	109.5	137.6	145.6
8-foot T12	Residential	46.1	24.9	--	21.2	--
	Commercial	262.4	122.5	--	139.9	--
	Industrial	346.0	161.5	--	184.5	--
8-foot T12 high output	Commercial	393.6	--	141.2	--	252.4
	Industrial	519.0	--	186.2	--	332.9

Baseline lamp type	Sector	Baseline per-unit annual energy use (kWh)	LED per-unit annual energy use (kWh)		Per-unit annual energy savings (kWh)	
			Type A	Type B	Type A	Type B
8-foot T8	Residential	29.2	20.7	23.5	8.5	5.6
	Commercial	163.3	100.2	131.8	63.1	31.4
	Industrial	233.2	143.1	188.3	90.1	44.9
8-foot T8 high output	Commercial	274.9	--	130.3	--	144.6
	Industrial	392.7	--	186.2	--	206.5

For pin-based CFLs, we evaluated only ballast-compatible LED replacements since we found 100% ballast compatibility. We used the 2015 LMC to estimate average operating hours and baseline lamp wattages, and we estimated the wattages of LED replacement lamps based on products available in the market. Table C8 shows our assumptions for annual operating hours; wattages and per-unit annual energy use for baseline CFLs and LED replacements; and the resulting per-unit annual energy savings.

Table C8. Per-unit annual energy savings for CFLs

Baseline lamp type	Sector	LED replacement type	Annual operation (hrs)	Wattage (W)		Per-unit annual energy use (kWh)		Per-unit annual energy savings (kWh)
				CFL	LED	CFL	LED	
Pin-based	Residential	Ballast compatible	803	22	12	17.7	9.6	8.0
	Commercial	Ballast compatible	4,453	26	12	115.8	53.4	62.3

PER-UNIT INCREMENTAL COSTS

We estimated per-unit incremental costs based on prices of representative lamps from major retailers. For LFLs, we collected data on both fluorescent and LED lamps for each baseline lamp category from retailers including big box stores (Home Depot, Lowe's, Walmart), hardware stores (Ace Hardware, True Value), Grainger, Office Depot, and online retailers (e.g., Amazon, 1000bulbs.com). The representative lamps include products sold in packs of one or two as well as those sold in multi-packs (e.g., 10, 25). We calculated average lamp prices for singles/two-packs and for multi-packs. For the residential sector, we assumed that some consumers would buy lamps singly or in two-packs, while others would buy multi-packs. Therefore, to develop prices for the residential sector, we averaged the average price of singles/two-packs and the average price of multi-packs. For the commercial and industrial sectors, we assumed that purchasers would buy lamps in multi-packs.

For LED lamps, we incorporated price declines based on DOE's solid-state lighting forecast, which projects declines of 25%, 20%, and 33% for general-purpose LEDs, four-foot TLEDs, and TLEDs larger than four feet, respectively, between 2020 and 2025 (DOE 2019). We assumed constant prices after 2025. For Type B linear LEDs, we incorporated the additional cost of a fuse kit, which protects the installer if a fluorescent lamp is reinstalled in the future. For Type B linear LEDs, we incorporated the additional labor cost to rewire the fixture to bypass the existing fluorescent ballast, based on information from GE on the time to install Type A and Type B LEDs and hourly labor rates from DOE's analysis for the 2021 notice of final determination for fluorescent lamp ballasts (DOE 2020c).

Table C9 shows our assumptions for the costs of baseline LFLs and Type A and Type B LED lamps, the cost of a fuse kit and the additional labor costs for Type B LED lamps, and the resulting per-unit incremental costs for Type A and Type B LED lamps for each LFL category in 2023.

Table C9. Per-unit incremental costs for LFLs in 2023

Baseline lamp type	Sector	Cost of baseline lamp (2020$)	Cost of Type A LED lamp (2020$)	Cost of Type B LED lamp (2020$)	Additional costs for Type B LED lamps (2020$)		Per-unit incremental cost (2020$)	
					Fuse kit	Labor	Type A	Type B
4-foot T12 – 40 W	Residential	4.98	7.26	--	--	--	2.28	--
	Commercial	3.74	6.33	--	--	--	2.59	--
4-foot T12 – 34 W	Commercial	2.67	6.33	--	--	--	3.67	--
4-foot T8	Residential	4.86	6.04	7.15	2.47	10.14	1.18	14.90
	Commercial/ industrial	4.22	4.76	5.16	2.47	9.46	0.54	12.87
4-foot T5	Residential	10.20	10.68	11.33	2.47	10.14	0.48	13.73
	Commercial	8.08	10.37	11.33	2.47	9.46	2.29	15.17
4-foot T5 high output	Commercial/ industrial	5.71	10.32	10.99	2.47	9.46	4.61	17.20
8-foot T12	Residential	10.03	28.43	--	--	--	18.40	--
	Commercial/ industrial	9.31	23.13	--	--	--	13.82	--
8-foot T12 high output	Commercial/ industrial	10.50	--	19.60	2.47	9.46	--	21.03
8-foot T8	Residential	9.36	28.43	21.59	2.47	10.14	19.07	24.83
	Commercial/ industrial	8.73	23.13	21.59	2.47	9.46	14.41	24.79
8-foot T8 high output	Commercial/ industrial	11.46	--	19.60	2.47	9.46	--	20.06

Table C10 shows our assumptions for the costs of baseline CFLs and LED replacements and the resulting per-unit incremental cost for each CFL category in 2023.

Table C10. Per-unit incremental costs for CFLs in 2023

Baseline lamp type	Sector	LED replacement type	Cost of baseline lamp (2020$)	Cost of LED lamp (2020$)	Per-unit incremental cost (2020$)
Pin-based	Residential	Ballast compatible	5.25	8.75	3.49
	Commercial	Ballast compatible	5.73	8.75	3.02

STATE-BY-STATE IMPACTS

To calculate state-by-state energy savings and costs, we allocated the national sales of each lamp type to each state using U.S. Census and energy consumption survey data. For residential lamps, we used the number of households in each state to allocate product sales.[14] We allocated commercial lamp sales to the four census regions based on regional commercial lighting electricity consumption from the 2012 Commercial Building Energy Consumption Survey (CBECS) (EIA 2015). We then allocated regional sales to individual states using state-by-state commercial electricity sales (EIA 2021b). For lamps used in the industrial sector, we first allocated sales to the four census regions based on regional facility lighting demand from the 2018 Manufacturing Energy Consumption Survey (MECS) (EIA 2021a). We then allocated regional sales to individual states based on state-by-state industrial electricity sales (EIA 2021b).

We calculated state-by-state mercury and CO_2 emissions reductions from electricity savings by multiplying annual electricity savings by respective state-by-state average emissions factors. We calculated emissions factors for each year of the analysis period for each of the EIA Electricity Market Module (EMM) regions by dividing the projected electric power sector emissions by the electric power sector generation and multiplying this value by a ratio of regional imports to exports using EIA's 2021 Annual Energy Outlook (AEO), as shown in the equation below:

*Regional emissions factor = Power sector emissions / Electric power sector generation * (Electric power sector generation for customer + Regional imports) / (Electric power sector generation for customer + Regional exports)*

For the states that span more than one EMM region, we calculated weighted-average emissions factors based on the division of electricity sales in each state. For Alaska and Hawaii, which are not included in the EMM regions, we used CO_2 output emissions for 2019

[14] We used the 2015–2019 Census 5-Year Estimate: www.census.gov/quickfacts/fact/dashboard/US/HSD410217.

from eGRID to calculate CO_2 emissions factors, and we calculated mercury emissions factors using the 2017 EPA air emissions inventory and each state's electricity generation.[15] We adjusted the mercury and CO_2 emissions factors for Alaska and Hawaii for the average U.S. change in emissions rates from 2019 and 2017, respectively, to 2020. For future years, we assumed a rate of change of emissions factors for Alaska and Hawaii equivalent to the U.S. average. Table C11 shows the state-by-state emissions factors for 2030 and 2035.

[15] EPA's eGRID Data Explorer is available at: www.epa.gov/egrid/data-explorer. EPA's air emissions inventory is available at: www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data.

Table C11. State-by-state emissions factors in 2030 and 2035 for electricity savings

	2030 emissions factors		2035 emissions factors	
State	Hg (lbs/GWh)	CO_2 (MMT/TWh)	Hg (lbs/GWh)	CO_2 (MMT/TWh)
Alabama	0.0011	0.319	0.0010	0.295
Alaska	0.0028	0.270	0.0026	0.252
Arizona	0.0009	0.152	0.0000	0.108
Arkansas	0.0005	0.338	0.0005	0.308
California	0.0000	0.170	0.0000	0.143
Colorado	0.0020	0.339	0.0015	0.298
Connecticut	0.0000	0.085	0.0000	0.085
Delaware	0.0029	0.214	0.0032	0.205
District of Columbia	0.0029	0.214	0.0032	0.205
Florida	0.0010	0.365	0.0008	0.318
Georgia	0.0009	0.305	0.0008	0.279
Hawaii	0.0006	0.467	0.0005	0.437
Idaho	0.0009	0.246	0.0007	0.229
Illinois	0.0013	0.253	0.0013	0.259
Indiana	0.0032	0.481	0.0032	0.502
Iowa	0.0024	0.350	0.0023	0.349
Kansas	0.0021	0.303	0.0021	0.303
Kentucky	0.0023	0.397	0.0020	0.390
Louisiana	0.0004	0.351	0.0004	0.319
Maine	0.0000	0.085	0.0000	0.085
Maryland	0.0028	0.228	0.0030	0.221
Massachusetts	0.0000	0.085	0.0000	0.085
Michigan	0.0025	0.468	0.0022	0.441
Minnesota	0.0022	0.338	0.0022	0.338
Mississippi	0.0011	0.361	0.0010	0.336
Missouri	0.0030	0.435	0.0030	0.451
Montana	0.0005	0.127	0.0005	0.121
Nebraska	0.0027	0.380	0.0026	0.368
Nevada	0.0011	0.291	0.0009	0.269

State	2030 emissions factors		2035 emissions factors	
	Hg (lbs/GWh)	CO_2 (MMT/TWh)	Hg (lbs/GWh)	CO_2 (MMT/TWh)
New Hampshire	0.0000	0.085	0.0000	0.085
New Jersey	0.0029	0.214	0.0032	0.205
New Mexico	0.0010	0.202	0.0005	0.167
New York	0.0000	0.264	0.0000	0.146
North Carolina	0.0016	0.270	0.0012	0.256
North Dakota	0.0027	0.376	0.0026	0.371
Ohio	0.0020	0.353	0.0018	0.361
Oklahoma	0.0012	0.269	0.0011	0.251
Oregon	0.0000	0.070	0.0000	0.063
Pennsylvania	0.0026	0.254	0.0028	0.250
Rhode Island	0.0000	0.085	0.0000	0.085
South Carolina	0.0016	0.270	0.0013	0.258
South Dakota	0.0027	0.377	0.0025	0.364
Tennessee	0.0024	0.414	0.0020	0.401
Texas	0.0014	0.323	0.0013	0.291
Utah	0.0012	0.304	0.0009	0.284
Vermont	0.0000	0.085	0.0000	0.085
Virginia	0.0005	0.281	0.0004	0.228
Washington	0.0000	0.070	0.0000	0.063
West Virginia	0.0020	0.353	0.0018	0.361
Wisconsin	0.0022	0.333	0.0021	0.334
Wyoming	0.0013	0.310	0.0010	0.286

We calculated electricity bill savings using state-by-state electricity prices for the residential, commercial, and industrial sectors. We used the AEO 2021 price projections to calculate projected electricity prices for each of the EMM regions for each year of the analysis period relative to 2019 prices (from AEO 2020). We then applied the relative regional price projections to the 2019 average retail price of electricity by state.[16] For the states that span more than one EMM region, we calculated weighted-average changes in prices based on the division of electricity sales in each state. Because Alaska and Hawaii are not included in the EMM regions, for these states we assumed that the rate of change of electricity prices would be equivalent to the U.S. average. Table C12 shows state-by-state electricity prices by sector for 2030 and 2035.

Table C12. State-by-state electricity prices for the residential, commercial, and industrial sectors in 2030 and 2035

	2030 electricity prices (2020 cents/kWh)			2035 electricity prices (2020 cents/kWh)		
State	Residential	Commercial	Industrial	Residential	Commercial	Industrial
Alabama	11.43	10.57	5.42	11.17	10.19	5.26
Alaska	22.98	19.95	16.54	23.05	19.81	16.46
Arizona	12.77	8.97	4.69	13.07	9.01	4.87
Arkansas	10.39	9.52	7.03	10.42	9.52	7.09
California	21.96	18.61	15.71	22.67	18.67	15.52
Colorado	11.76	8.72	5.92	12.02	8.79	6.17
Connecticut	23.78	17.40	10.64	24.52	17.50	10.50
Delaware	13.88	11.59	8.19	14.16	11.67	8.06
District of Columbia	14.36	14.90	8.75	14.64	15.01	8.61
Florida	11.27	8.98	7.67	11.03	8.70	7.52
Georgia	10.86	9.32	5.73	10.59	8.97	5.55
Hawaii	32.15	29.45	25.16	32.24	29.24	25.03
Idaho	10.84	7.32	5.16	11.33	7.48	5.42
Illinois	12.43	9.66	6.86	12.13	9.57	6.84
Indiana	11.86	10.08	6.62	11.57	9.70	6.36
Iowa	12.59	9.24	5.85	12.67	9.21	5.91
Kansas	11.78	9.41	6.63	11.50	9.07	6.50

[16] EIA data on average retail electricity prices by sector are available at: www.eia.gov/electricity/sales_revenue_price/pdf/table4.pdf.

State	2030 electricity prices (2020 cents/kWh)			2035 electricity prices (2020 cents/kWh)		
	Residential	Commercial	Industrial	Residential	Commercial	Industrial
Kentucky	9.37	8.78	4.63	9.27	8.56	4.53
Louisiana	10.47	9.79	6.11	10.51	9.78	6.16
Maine	19.45	13.33	7.30	20.06	13.40	7.20
Maryland	14.29	11.84	8.19	14.54	11.91	8.06
Massachusetts	23.83	17.45	11.69	24.57	17.55	11.53
Michigan	15.24	10.79	6.66	14.96	10.47	6.52
Minnesota	13.03	9.46	6.60	12.93	9.28	6.58
Mississippi	10.76	10.21	5.79	10.69	10.04	5.75
Missouri	10.44	8.26	6.37	10.17	7.93	6.16
Montana	11.20	9.64	4.32	11.74	9.78	4.47
Nebraska	11.12	8.28	6.88	11.62	8.62	7.22
Nevada	13.42	7.69	5.31	13.96	7.86	5.59
New Hampshire	21.80	16.54	10.37	22.48	16.64	10.23
New Jersey	17.54	14.87	10.81	17.88	14.98	10.64
New Mexico	12.76	9.02	4.66	12.96	9.05	4.79
New York	18.54	17.10	6.16	19.48	18.04	6.33
North Carolina	11.34	8.71	6.10	11.12	8.42	5.96
North Dakota	10.65	8.51	7.21	11.05	8.79	7.49
Ohio	11.62	9.13	6.09	11.54	8.98	5.93
Oklahoma	10.35	8.09	5.24	10.37	8.09	5.31
Oregon	11.06	8.19	4.50	11.69	8.33	4.68
Pennsylvania	14.60	9.89	6.57	14.78	9.91	6.45
Rhode Island	23.63	17.01	12.35	24.36	17.11	12.18
South Carolina	12.87	10.45	5.90	12.60	10.09	5.77
South Dakota	11.88	8.92	6.98	12.40	9.27	7.32
Tennessee	9.14	8.91	4.51	9.02	8.67	4.43
Texas	11.97	7.74	6.13	11.99	7.70	6.15
Utah	11.71	7.97	5.24	12.21	8.15	5.52
Vermont	19.26	16.60	8.75	19.85	16.69	8.63
Virginia	12.62	8.17	6.90	12.75	8.19	6.69
Washington	9.75	8.10	3.69	10.31	8.24	3.84

	2030 electricity prices (2020 cents/kWh)			2035 electricity prices (2020 cents/kWh)		
State	Residential	Commercial	Industrial	Residential	Commercial	Industrial
West Virginia	10.56	8.60	5.59	10.48	8.46	5.45
Wisconsin	14.10	9.76	6.38	13.89	9.50	6.31
Wyoming	12.27	9.07	5.80	12.74	9.26	6.10

Appendix D. State Policies

STATE POLICY TYPES

Prohibiting the sale of certain mercury-added products. Most often these target mercury thermometers, electric switches and relays, and novelty products. Some states set broad mercury content limits that all products must comply with; however, fluorescent lamp exemptions are common.

Collection, disposal, and/or recycling requirements. These restrict the disposal of mercury-added products and/or require specialized mercury collection and recycling programs.

Information disclosure. This type of policy requires labels on mercury-added product packaging and/or requires manufacturers to submit information to the state describing mercury-added products offered for sale and their mercury content.

State building and/or school alternative purchasing requirement. This approach requires or encourages state facilities and/or schools to purchase mercury-free or lower-mercury products when such alternatives exist.

STATE POLICY EXAMPLES

Legislative Findings on Mercury

Maryland: "The General Assembly finds that:

(1) Mercury is a persistent and toxic pollutant that bioaccumulates in the environment;

(2) Consumption of mercury–contaminated fish poses a significant health threat;

(3) Combustion of municipal and other solid waste is a source of mercury pollution;

(4) Both industry and government are working to reduce the content of mercury in products and to control the release of mercury into the environment;

(5) Accidental mercury spills, breakages, and releases have occurred at schools in the United States, exposing students, teachers, and administrators to mercury emissions; and

(6) Removal of mercury and mercury–containing products from the waste stream prior to combustion or disposal is an effective way to reduce mercury pollution." (Code of Maryland, Article Environment, Section 6-904)

Disposal Ban

New York: Waste products containing mercury are considered hazardous waste and cannot be disposed of in the same manner as other solid waste. Mercury products cannot be incinerated. Waste management facilities must store, recycle, or dispose of mercury-added products in accordance with state rules. Monetary penalties of up to $500 per violation may be levied for repeated violations. Exemptions from these disposal provisions include fluorescent lamp disposal from households and businesses with 100 or fewer employees that produce 15 or fewer waste lamps per month. (Laws of New York, Article 27, Title 21)

Labeling Requirement

Connecticut: "Manufacturers of fluorescent lights and high-intensity discharge lamps shall meet the labeling requirements of this section by labeling the product packaging and placing the symbol 'Hg' on each lamp." (Connecticut General Statute, Chapter 446m, Sec. 22a-619)

Ban on Sale of Certain Mercury Products

Rhode Island: "(a) No mercury-added product shall be offered for final sale or use or distributed for promotional purposes in Rhode Island if the mercury content of the product exceeds:

(1) One gram (1000 milligrams) for mercury-added fabricated products or two hundred fifty (250) parts per million (ppm) for mercury-added formulated products, effective January 1, 2006.

(2) One hundred (100) milligrams for mercury-added fabricated products or fifty (50) parts per million (ppm) for mercury-added formulated products, effective July 1, 2007; and

(3) Ten (10) milligrams for mercury-added fabricated products or ten (10) parts per million (ppm) for mercury-added formulated products, effective July 1, 2009."

[. . .]

"(d)(1) Fluorescent lamps, cold cathode low pressure mercury discharge lamps/neon lamps and high intensity discharge (HID) lamps, including metal halide, high pressure sodium, and mercury vapor types, shall be exempt from the requirements of subsection (a) of this section. As of January 1, 2010, the mercury content of fluorescent bulbs, cold cathode low pressure mercury discharge lamps/neon lamps shall either not exceed one hundred (100) milligrams or the manufacturer shall comply with the exemption requirements pursuant to subsection (f) of this section. The department may issue rules requiring more stringent mercury content limits for such bulbs or tubes, consistent with limits issued by other states and the European Union.

(2) Specialized lighting used in the entertainment industry, such as metal halide lights, shall be exempted from the requirements of subsection (a) of this section." (Rhode Island General Law, Title 23, Chapter 24.9-7)

Collection and/or Recycling Program

Washington: "(1) Every producer of mercury-containing lights sold in or into Washington State for retail sale in Washington State must participate in a product stewardship program for those products, operated by a stewardship organization and financed in the manner provided by RCW 70A.505.050. Every such producer must inform the department of the producer's participation in a product stewardship program by including the producer's name in a plan submitted to the department by a stewardship organization as required by RCW 70A.505.040. Producers must satisfy these participation obligations individually or may do so jointly with other producers.

(2) A stewardship organization operating a product stewardship program must pay all administrative and operational costs associated with its program with revenues received from the environmental handling charge described in RCW 70A.505.050. The stewardship organization's administrative and operational costs are not required to include a collection location's cost of receiving, accumulating and storing, and packaging mercury-containing lights. However, a stewardship organization may offer incentives or payments to collectors. The stewardship organization's administrative and operational costs do not include the collection costs associated with curbside and mail-back collection programs. The stewardship organization must arrange for collection service at locations described in subsection (4) of this section, which may include household hazardous waste facilities, charities, retailers, government recycling sites, or other suitable private locations. No such entity is required to provide collection services at their location. For curbside and mail-back programs, a stewardship organization must pay the costs of transporting mercury-containing lights from accumulation points and for processing mercury-containing lights collected by curbside and mail-back programs. For collection locations, including household hazardous waste facilities, charities, retailers, government recycling sites, or other suitable private locations, a stewardship organization must pay the costs of packaging and shipping materials as required under RCW 70A.505.070 or must compensate collectors for the costs of those materials, and must pay the costs of transportation and processing of mercury-containing lights collected from the collection locations.

(3) Product stewardship programs shall collect unwanted mercury-containing lights delivered from covered entities for recycling, processing, or final disposition, and not charge a fee when lights are dropped off or delivered into the program.

(4) Product stewardship programs shall provide, at a minimum, no-cost services in all cities in the state with populations greater than ten thousand and all counties of the state on an ongoing, year-round basis.

(5) Product stewardship programs shall promote the safe handling and recycling of mercury-containing lights to the public, including producing and offering point-of-sale educational materials to retailers of mercury-containing lights and point-of-return educational materials to collection locations.

(6) All product stewardship programs operated under approved plans must recover their fair share of unwanted covered products as determined by the department.

(7) The department or its designee may inspect, audit, or review audits of processing and disposal facilities used to fulfill the requirements of a product stewardship program.

(8) No product stewardship program required under this chapter may use federal or state prison labor for processing unwanted products.

(9) Product stewardship programs for mercury-containing lights must be fully implemented by January 1, 2015." (RCW, Title 70a, Chapter 70A.505, Section 70A.505.030)

Information Disclosure

Connecticut: "(a) On and after January 1, 2003, no person shall offer any mercury-added product for sale or distribute any such product for promotional purposes in this state unless the manufacturer or its designated industrial trade group gives prior notification in writing to the commissioner, or the regional multistate clearinghouse described in section 22a-614 as provided in this section. Such notification, in a form prescribed by the commissioner, shall at a minimum include (1) a brief description of the product or category of products to be offered for sale or distributed; (2) an identification of each product by its mercury content in one of the following ranges: Less than zero to five milligrams, greater than five milligrams to ten milligrams, greater than ten milligrams to fifty milligrams, greater than fifty milligrams to one hundred milligrams, greater than one hundred milligrams to one thousand milligrams, and greater than one thousand milligrams; (3) the actual total amount of mercury in each product; and (4) the name and address of the manufacturer and the position, address and phone number of a contact person at the manufacturer. The manufacturer or its designated industrial trade group shall revise the information in the notification whenever there is significant change in the information or when requested by the commissioner or the regional multistate clearinghouse." (Connecticut General Statute, Chapter 446m, Sec. 22a-615)

Alternative Purchasing for State Buildings and/or Schools

Massachusetts: Except for fluorescent lighting, public schools are prohibited from purchasing mercury-added products. (Massachusetts General Law, Part 1, Title 2, Chapter 21H, Section 6G)

Maine: "When making purchasing decisions on mercury-added lamps and ballasts, the Department of Administrative and Financial Services, in consultation with the [Department of Environmental Protection] department and the Public Utilities Commission, shall request information on mercury content, energy use, lumen output and lamp life from potential suppliers and shall issue specifications and make purchasing decisions that favor models at comparable cost with high energy efficiency, lower mercury content and longer lamp life. Information obtained on mercury content, energy use and lamp life must be made available by the Department of Administrative and Financial Services to other purchasers who purchase a large number of mercury-added lamps. This information must also be posted on the State's publicly accessible website." (Maine Revised Statutes, Title 38, Chapter 16-B, Section 1672)